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GENERAL ZOÖLOGY

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BY

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PREFACE

The present volume is the product of some years' experience in developing an introductory course in zoology designed to meet the needs of general college students and at the same time to satisfy the technical requirements of various groups of pre-professional students, especially those preparing for medicine. The foundation for such a course must be laid in the actual study of animal forms in the laboratory but the limitation in time precludes the presentation and demonstration of many important and interesting aspects of the subject by the usual laboratory methods. For this reason the author, sharing the experience of others, has found it advisable to devote two or three lecture or recitation periods weekly to the enlargement and rounding out of the student's knowledge of the subject by class-room discussions of those phases of zoology not adequately dealt with in the laboratory. The problem of a suitable text for this work has been met by the compilation of the contents of this book, which is a rather condensed account of some of the outstanding facts and principles of zoology, selected and arranged to serve the student as a guide; the form of the text having been kept as flexible as possible to permit of expansion or extension in whatever direction the instructor may see fit. The references listed at the end of each chapter are easily available works which the author has been in the custom of assigning for collateral reading.

The book begins with a consideration of such general topics as morphology and physiology, the protoplasmic doctrine, the cell doctrine, taxonomy and adaptation; followed by an outline of organology illustrated by examples from common laboratory animals, considered largely from the morphological side. Then follows a section dealing primarily with the functional side of the animal organism, centering in metabolism. Next come the main facts of ontogenesis, followed in turn by a discussion of phylogenesis, evolution and heredity. To cover this ground takes the greater part of a year, the remainder of which is devoted to a general survey of the animal kingdom, as outlined in the final chapter, paying particular attention to life histories and the sys-

tematic side of zoology, which the author believes should form an integral part of the course. Such a systematic survey can best be undertaken toward the end of the year when the student through his laboratory work has obtained sufficient familiarity with animal forms and taxonomy to make it worth while. Incidentally there is perhaps no better way to review or summarize the course and to bring out vividly the applications of biological principles. The author realizes that principles are based upon facts and that logically facts should come first; the plan of presentation followed here is a compromise which is successful with beginning students and which at the same time does not violate standards of scientific method.

In the laboratory the endeavor is made to have the student obtain a substantial knowledge of a relatively few animal forms as whole organisms rather than a smattering acquaintance with parts of many. Selection of animal forms for laboratory study is a matter of judgment guided by experience. The author has found it best to begin with a relatively large animal, like the frog, then turning to Protozoa and working up the scale. This general program is broken into from time to time with special demonstrations, collecting trips and visits to the zoological garden. For the laboratory work mimeographed directions are used similar to those used in the work in other places.

Naturally it is not always possible to correlate lecture and laboratory work but the class-room instructor constantly bears in mind what the student is doing in the laboratory and, so far as possible, makes full use of the student's laboratory experience in dealing with the subject under discussion. Free use of special demonstrations help to obviate this difficulty.

In the compilation of the material for this book the author has made use of many sources which are acknowledged in the text and in the lists of references at the ends of chapters. The majority of the illustrations are new drawings based upon the author's material or figures of others; the remainder have been taken directly from other works with the permission of the publishers whose courteous cooperation is duly appreciated. The author is also indebted to his wife for valuable assistance of a miscellaneous sort at each stage of the book's progress; and to Dr. C. V. Piper for helpful editorial suggestions.

CINCINNATI, O. H. L. WIEMAN.
June, 1925.

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GENERAL ZOÖLOGY

CHAPTER I

THE STUDY OF ZOÖLOGY

"Biology" is derived from two *Greek* words, $\beta\iota o\varsigma$ (bios), life, and $\lambda o\gamma o\varsigma$ (logos), discourse, and was introduced into general use by the renowned French naturalist, Lamarck (1744–1829), to fill the need of a satisfactory term to designate the study of living things and life processes. Biology is the science of organisms. Since animals and plants constitute the two general categories of organisms, or living things, then, in order to learn facts about life, observations must be based upon phenomena exhibited by organisms. Our senses tell us that life is manifested only in the bodies of animals and plants or, put in another way, that life is always associated with the materials composing the organic body. Matter without life is common enough, but life without matter is unknown to science. Therefore, since life, as we know it, is indissolubly linked with matter, any conclusions reached regarding the nature of life must rest upon careful studies of the structure and function of the animal and plant body. *Zoölogy*, from $\zeta\omega o\nu$ (zoös), animal, and $\lambda o\gamma o\varsigma$ (logos), discourse, deals with the animal side of biology, while *Botany* is concerned with plants.

Aim.—The common aim of all biological studies is the unraveling of the problem of the *origin* and *nature* of life, a problem whose complete solution would be the crowning achievement of mankind. This problem of problems has been attacked from many angles and in many ways, but the broad general lines of approach are relatively few in number, and may be summarized as follows:

1. *Protoplasm*, the study of the *physical* and *chemical* properties of the living matter of which organisms are composed and with which life is always associated.

2. *Morphology*, the study of the form and structure of the bodies of animals and plants. This is commonly subdivided into:

a. Gross anatomy, which is morphological study in its broad aspects;

b. Microscopic anatomy, or histology, the study of the more minute structure of the tissues and organs;

c. Cytology, the study of the finest structural details of cells, the morphological units of which tissues and organs are composed;

d. Embryology, the study of the development of an organism; the study of embryogeny.

3. *Physiology*, the study of the functions of organs considered separately and in relation to the organism as a whole, deals with the processes of waste and repair in the living things, food, and the sources and transformation of energy.

4. *Evolution*, the study of the processes by which the great wealth and diversity of life, and its distribution in time and space, have been brought about. Such an investigation involves, among other things, a search into the past history of the earth and its inhabitants. This study leads into the field of *Paleontology*, the study of prehistoric forms of life, a record of whose existence has been preserved in fossils embedded in the earth's crust.

5. *Genetics*, the science dealing with the nature of the hereditary relation between parent and offspring, must also be studied. This field at the present time enlists the efforts of a large corps of workers.

These various methods of approaching the subject are followed in both Botany and Zoölogy, but since this book deals with animal organisms its scope is largely confined to the zoölogical aspects of biology.

Morphology and Physiology.—The study of animal or plant organization may be developed, along two general lines namely; those relating to structure, morphology, and those concerning function, physiology. In general, morphological studies deal mainly with the statics of living things, while physiology has to do with dynamics. Such a classification is artificial, of course, and, therefore, to only a certain extent useful. The animal or plant organism is a unit of which its morphology and physiology are merely different aspects, and for this reason a purely morphological study may lead to erroneous conclusions unless checked by physiological observations. It happens, however, in order to

understand the working in whole or in part of a complicated machine like the body of a man or a frog, that it is necessary first of all, for purely practical reasons, to obtain a knowledge of how the machine is put together by the relatively simple process of taking it apart. Hence, it is customary to begin the laboratory study of an animal with a careful examination of its anatomy; but since questions of function constantly arise while dissections are being made, it is important for the student always to bear in mind the possible or probable physiological significance of structural relationships, even though complete answers to questions thus raised are not practicable at the time.

Morphology and physiology, then, are merely convenient terms for classifying two fairly distinct groups of phenomena and consequently, the assignment of a field of study under one head or the other is always subject to some limitation. Thus, embryology is ordinarily considered a morphological subject, because its study consists largely of examination and study in considerable detail of the form and structure of embryos at different stages of development; but since this is done for the purpose of piecing together a history of the *process* of development, an embryological study that does not give due weight to the physiological aspects of development becomes merely a series of lifeless descriptions of embryo-anatomy. In other words, morphology and physiology are *complementary*, and a consideration of both is essential in arriving at an understanding of an animal's organization.

By means of gross and microscopic dissections of an animal, and carefully planned laboratory experiments, a detailed knowledge of its anatomy and physiology may be obtained; yet a far from satisfactory conception of the animal as an organism is gained unless laboratory observations are supplemented by studying the animal in its natural state in the field, and thus noting its relationships to other organisms and its environment generally; in other words, its *ecology*. But even after exhausting these avenues of approach, the problem of the organism still presents difficulties which can only be removed—and not completely at that—by applying all the refinements of technique of the sciences of *physics* and *chemistry*. The study of living things is beset with difficulties many and diverse because of the presence of so many *variable* factors, and it is not surprising, therefore, that the pursuit of the subject involves in one form or another not only the combined resources of what are ordi-

narily considered the biological sciences, but those of other fields as well, especially chemistry and physics.

Biological Viewpoint.—Biology, like other fields of study, is not without its tenets or points of view. A biologic concept may rest upon a very unsteady base, which may be strengthened or weakened from day to day by the discovery of new facts, but the biologist, like the chemist or physicist, is justified in clinging to a theory or hypothesis so long as it serves to provide a working basis for further investigation. The purpose in mentioning at this point some generally accepted biological principles, such as the *Protoplasmic Doctrine*, the *Cell Doctrine*, *Evolution*, and *Taxonomy*, is not to limit the reader's horizon by compelling him to view the subject through biological spectacles, but rather to provide him with a guide in the form of a brief sketch of the nature of some broad biological concepts that represent landmarks in past achievement and sign posts to future discovery.

The Protoplasmic Doctrine.—Protoplasm is the living substance of which the bodies of animals and plants are composed, the common structural unit of which is the cell. Cells are bricks made of protoplasmic clay.

Physical Properties.—Isolated, uncolored cells viewed in the living state through a microscope appear as faintly grayish, jelly-like masses in which granules are suspended. Sometimes a streaming or flowing movement within the cell can be seen. Protoplasm is heavier than water and somewhat more refractive to light.

So far as its physical state is concerned, protoplasm is *colloidal*, which means that (1) instead of being in the form of a true solution, it consists of suspensions of molecular aggregates of relatively large size, varying roughly between 0.0001 and 0.000001 millimeter in diameter; (2) it diffuses slowly or not at all through animal membranes; (3) it changes from a fluid or *sol* state to a more solid or *gel* state and back again.

Protoplasm, therefore, from the purely physical side, resembles substances like glue or gelatin rather than *crystalloids* like cane sugar or sodium chloride. When living cells are subjected to dissection under the microscope with extremely fine needles, the more solid portions can be drawn out into thin threads having considerable tenacity. Sometimes the mere touch of the needle to the cell causes liquefaction, or the reverse change, gelation, may occur with extreme rapidity. The *reversibility* of the change

from solid to liquid and vice versa is one of the striking characteristics of protoplasm and is of essential importance in maintaining the living state. The principal liquid involved in these changes is water.

Chemical Properties.—As to its chemistry, protoplasm is not a single, definite chemical compound, but consists of a number of substances combined in a colloidal complex, the percentage of the different constituents varying somewhat in different kinds of protoplasm. *Water* forms the bulk of protoplasm, being present in from 70 to 90 per cent. *Inorganic salts*, like the sulphates, chlorides, phosphates, and carbonates of sodium, potassium, magnesium, calcium, and iron, form about 1 per cent of the whole. Small amounts of iodine, manganese, copper, zinc, barium, and silicon are present in varying amounts. The remaining constituents, namely, *proteins*, *fats*, and *carbohydrates*, are *organic* in nature; of these the most important is protein. Protein is a very complex substance which has never been synthesized, but it is known to contain carbon, hydrogen, oxygen, and nitrogen. Fats and carbohydrates both contain carbon, hydrogen, and oxygen, but combined in different ways. Carbohydrates include starches and sugars.

From this it may be seen that there is no chemical element in protoplasm that is not found in inorganic nature—there is no *vital* chemical element—but it is also true that the organic constituents, namely, protein, carbohydrates, and fat, are found only in or as the products of living matter. This means that the *atomic* or *molecular grouping* characterizing these organic constituents of protoplasm is something which is peculiar to living matter.

Metabolism.—Protoplasm is in a condition of perpetual change. The energy required by an animal to carry on its normal activities is released through chemical reactions which involve the formation of waste or excretory products like carbon dioxide, urea, etc., which are of no value to the body and can, therefore, be eliminated. This *loss in matter* and *energy* is made good by *food* taken into the body. The twofold process of *disintegration* and *reintegration* is called metabolism and always characterizes the living state. In metabolism the cells are not alternately broken into pieces and reconstructed anew, for the reason that reintegration keeps pace with disintegration. While the comparison is rather crude, the cells of the body may be likened to so many

vessels, the contents and constituents of which are constantly changing with loss and gain of substance and energy, but which at the same time maintain their form and structure.

Movement.—The power of movement is present in all living things, but more pronounced in animals. The foliage of plants moves in response to the stimulation of sunlight. Movement in organisms results from the liberation of energy in the living substance.

Growth.—Living things grow by *intussusception*, that is, by the intercalation of substances within the body. Inanimate objects grow by *accretion* or addition of particles to the outside.

Irritability.—Protoplasm has the property of irritability, the power to respond to stimuli. A *stimulus* is any disturbing influence, such as that produced by impact, heat, light, sound, electricity, chemical action, etc. Stimuli may be external or internal to the organism.

Reproduction.—Living things reproduce their own kind.

Size.—Finally, protoplasm, as it is seen in animals and plants, is modeled in a *determinate* size and structure. Living things are distinguished by a definite form which is reproduced generation after generation. Inanimate objects may be of almost any size as, for example, water may be in the form of a raindrop or a lake; a stone may be a pebble or a mountain.

Vitalism and Mechanism.—The above-mentioned properties differentiate living matter from non-living. They are the essential manifestations of life. It was formerly thought that the activities of living things are presided over and directed by some sort of *vital force*, such as the "soul" of Descartes or the "entelechy" of Driesch, but this idea is not generally accepted by biologists today. According to the *Vitalists*, a living thing is protoplasm plus *something*, but what this something is has never been seen, felt, weighed, or measured. Because its attributes have never been described in terms of physics and chemistry, any claims for its existence can be tolerated only on metaphysical grounds. But even granting that there is such a thing as a vital force or energy of a sort entirely unknown to science at the present time because of failure to detect it, a denial of its existence must not be attributed to narrowness on the part of scientists, but to the lack of satisfactory evidence. So long as evidence for the existence of this unknown form of energy is lacking, the scientist is compelled to do without it, since he can deal with

only those facts and factors in the problem of protoplasm which are amenable to scientific analysis and measurement. For this reason biologists incline toward what, for want of better term, is commonly known as the *mechanistic* theory of life, which implies that the phenomena of life are due to the sum total of the physical and chemical properties of the material substances composing protoplasm, even though it is frankly admitted that a complete explanation of all the vital phenomena in terms of chemistry and physics, or matter and energy, is at the present time far from accomplished. That such a goal is being approached, however, would seem to be indicated by the success with which scientific explanations are gradually replacing hypothetical vital forces in unraveling and interpreting the phenomena of life and explaining life processes in terms of chemistry and physics. Vitalism is slowly giving way to mechanism.

The Cell Doctrine. The simple proposition that the bodies of animals and plants are composed of cells and the products of cells, that is, extracellular substances, expresses the essential features of the *Cell Theory* as announced in 1838 by Mathias J. Schleiden, a botanist, and Theodor Schwann, a zoologist. The additions to the sum of knowledge of the morphology and the physiology of the cell since that time have increased to such an extent that the cell theory has become an instrument of greatest value for interpreting observations and discoveries in embryology, heredity, morphology, and physiology, with the natural result that today the cell doctrine implies attributes undreamed of by its authors.

The *cell* may be defined as a mass of protoplasm containing one or more nuclei. There is no one characteristic shape or form that describes the appearance of a cell. Some, like egg cells, are spherical or ellipsoidal, but most cells are quite different in shape. The shapes of the cells vary according to their functions and their spatial relations to other cells. The spherical shape of the frog's egg, for example, is undoubtedly correlated with the fact that it is deposited as a free cell in the water; while the flattened form of the pavement epithelium of the outer surface of the frog's skin is understood from its position on the surface of the frog's body. Nerve cells, on the other hand, are characterized by long processes which serve to bring all parts of the body under nervous control. Muscle cells are of still different form, which can be understood only after the action of

muscle cells has been observed. In general, the shape of each cell is adapted to its particular function, and its form becomes modified accordingly.

The *nucleus* is usually a centrally located rounded body embedded in the *cytoplasm*, which is the term applied to the remaining protoplasm of the cell. In most cells the nucleus is definitely bounded by a membrane; in simple organisms, like bacteria, the nuclear substance is scattered through the cytoplasm; in still others, as in the mammalian red corpuscles,

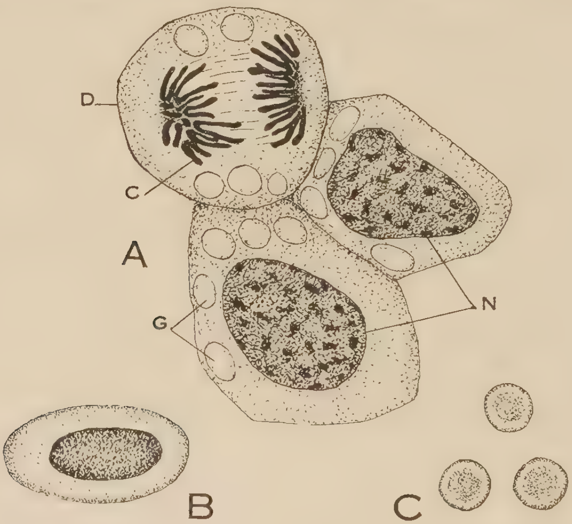


Fig. 1.—Cells. A, three cells from the outer layer of the skin of the salamander one of which (D) is dividing. C, chromosomes; G, yolk globules; N, nucleus; B, blood cell of the salamander, nucleated. C, human red blood cells, non-nucleated. × 900.

the nucleus is lacking, although it is present in earlier stages of the development of the corpuscle, before it enters the blood stream. The nucleus contains a substance called *chromatin*, which, unless the cell is dividing, consists of rather indistinct masses of ragged outline. In the course of cell division the chromatin becomes organized into very distinct bodies called *chromosomes* (Chap. XIII), which at the present time have a high theoretical importance in studies of heredity. The nucleus may contain a *nucleolus*, a structure of rounded appearance and unknown function. In the cytoplasm numerous rod-shaped objects called *mitochondria* are found, also *fat*, *oil globules*, and other substance of nutritive nature in varying amounts, depending on the char-

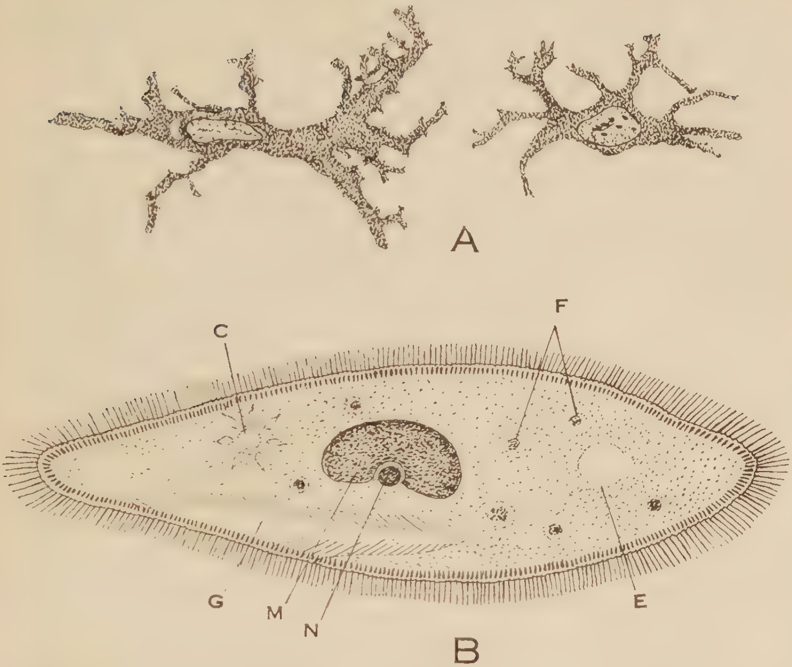


FIG. 2.—Cells. A, two pigment cells from the skin of the salamander. B, paramœcium, a ciliated protozoan, a single celled-animal. C, contractile vacuole, expanding; E, contractile vacuole, expanded; F, food vacuoles; G, gullet, a primitive alimentary tract; M, macronucleus; N, micronucleus. × 300. The contractile vacuoles are filled with cell fluid which is emptied on the outside when the vacuole contracts, thus maintaining an intra-cellular circulation. Food vacuoles are simple organs of digestion.

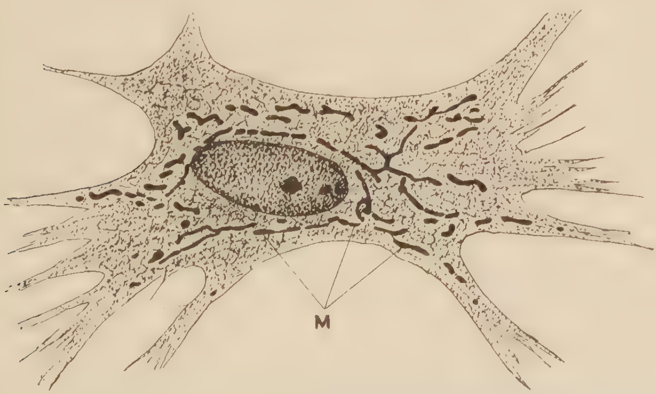


FIG. 3.—Endothelial cell from a tissue culture of the chick embryo, grown in a culture medium on a glass cover-slip inverted over a hollow-ground slide; stained to show mitochondria, M. × 1080. (*From a photo by W. H. Lewis.*)

acter of the cell. In cells of special function the cytoplasm develops *fibrils*, *cilia*, or *flagella*, etc., as the case might be. The entire body of a protozoan is composed of a single cell.

Cell Size.—Most cells are microscopic in size, but the limits in dimensions are wide. Thus, the unfertilized egg of the fowl, which is a cell, is approximately the size of the yolk of the laid egg, and is therefore macroscopic in size. On the other hand, the cells of animals generally, are visible only under the microscope. The common unit of linear measurement employed in microscopy is the *micron*, usually abbreviated as μ (Greek letter *mu*), whose value is 0.001 millimeter. Human red blood cells measure 7.5 to 8.5μ in diameter; leucocytes 10μ; while a skeletal muscle fiber, which is really a multinucleated cell, may be an inch long and 50μ in diameter.

Applications of the Cell Theory.—In 1844, Carl von Nageli made the statement that all cells come from preexisting cells, a conclusion which has been verified since and has become incorporated in the cell theory. The details of the process of cell reproduction were not clear at first and because of the difficulties involved the facts came to light rather slowly. In 1879, Eduard Strasburger, a botanist, announced definitely that nuclei arise only from preexisting nuclei, a conclusion confirmed by W. Flemming in studies of animal cells in 1882. It is largely due to the efforts of these two men that the complex details of cell division were worked out. A consideration of cell division is reserved for Chap. XIII and it need only be mentioned at this point that, as a rule, when a cell divides the product is two cells of equal size, each of which in the course of time by a process of growth, reaches the size of the parent cell.

In 1854, Newport made the observation in the frog that when the *spermatozoön* of the male unites with the *egg* of the female there results a *fertilized egg*, which is the starting point in the life of a new individual. In 1861, Gegenbauer showed that the egg is a cell and the same conclusion regarding the spermatozoön was reached in 1865 by Schweigger-Seidel and LaVallette St. George. Once the real significance of these observations was fully grasped, the cell doctrine assumed a position of vast importance in the study of embryology and heredity, because the egg and sperm cells contain all the *hereditary potentialities* that parents transmit to offspring. The problem of heredity centers in explaining how an adult organism develops from a cell.

It was not until 1861 that it was clearly demonstrated by Max Schultze that cells are really masses of protoplasm, and that protoplasm is essentially similar in all living organisms. This is a logical conclusion that binds the cell theory and the protoplasm doctrine together, and one that constitutes the very foundation of the scientific theory of life. Cells are both morphological and physiological units, and the structural and functional features of an organism are merely the sum total of the properties of the individual cells. The cell is the *unit of organization* common to all forms of life.

Evolution.—There exists abundant evidence for the belief that the present population of the earth, and the condition of the earth itself, are the results of a process of change or evolution that has extended over enormous periods of time. The evidence for this belief is too extensive to be considered at this point—the only purpose in mentioning the subject being to call attention to a very important and generally accepted biological principle. The theory of evolution implies that animals and plants were not always as they are now, but that they have *descended* from more primitive forms of life through the action of slow processes of *divergence* and *adaptation* accompanying changes in *environmental conditions.*

Evolution has been the guiding thought of biology for more than half a century, thanks largely to the painstaking work of the great English naturalist, Charles Darwin, whose publications, beginning with the "*Origin of Species*" in 1859, rank as the most notable contributions to biologic literature of the nineteenth century, and perhaps of all time.

Taxonomy.—The science of classification is known as taxonomy. The theory of evolution teaches that all living things have had a *common origin* in some simple form of protoplasm. From this hypothetical ancestral organism there first arose, presumably, the simpler forms of plant and animal life and from these in turn the higher forms. Thus it follows that a *relationship* of varying degree exists between all forms of life—even animals and plants being connected by simple unicellular forms, some of which combine both animal and plant characteristics. Lamarck (1744–1829) was the first to express this relationship diagrammatically by means of a tree, whose trunk divides almost at once into two main stems, one for the plant kingdom and one for the animal kingdom, each stem in turn sending out branches that represent

the subdivisions of plants and animals. Such a tree would show the relationships between organisms in a very exact manner if knowledge of the evolutionary processes were complete, but since this knowledge is at its best rather fragmentary the construction of the *tree of life* is a difficult matter and subject to continual alteration.

Descent.—When it is held that the higher animals are derived or descended from animals similar in form and organization, it is not meant that the lower animals living today are the ancestors of the higher ones. Thus, it would be incorrect to speak of monkeys or apes as the ancestors of man, although it is true that man is more closely related to them than to any other animals. The fact of the matter is that man and monkey probably had some *common ancestor* from which monkeys were evolved on one hand and man on the other—the common ancestor having in the mean time disappeared from the living fauna. Since the same principle applies to other groups of animals and plants, it follows that the part of the genealogical tree that represents the living population of the earth includes only the *twigs* —the trunk and its branches, representing the *connecting links* between living forms, having dropped out and become extinct.

Natural Affinities.—Evidence of relationship between organisms may be obtained from a study of living animals and plants. The great Swedish naturalist Linnaeus (1707–1778), who founded the modern system of classification, was not an evolutionist, but he was able nevertheless to classify animals and plants with a remarkable degree of accuracy by carefully noting their resemblances and differences. The point is, however, that these resemblances or *natural affinities*, as Darwin called them, find their rational explanation in the theory of evolution, with the result that the application of the evolution principle has had a clarifying effect on the problems of classification.

Species.—In the modern scheme of classification the species constitutes the basic group of individuals. A *species* may be simply defined as the offspring of similar parents. The members of different species resemble one another because they are descended from common ancestors. Species have become more or less sharply differentiated from all other species by the disappearance of intermediate forms. Owing to *variation*, the individuals composing a species are never identical, and the individual differences which constitute these variations make it

difficult to define the limits of a species. Such gradations among or between species are exactly what would be expected on an evolution basis; while, on the other hand, variations have been a stumbling block to upholders of the doctrine of *Special Creation*, who with Linnaeus believed that species did not develop gradually but were made outright, and that all species were, therefore, *fixed*. At present, the idea of a species being fixed is no longer accepted because of the vagueness of the boundaries between them but the employment of the term species is useful in describing the basic unit in the system of classification.

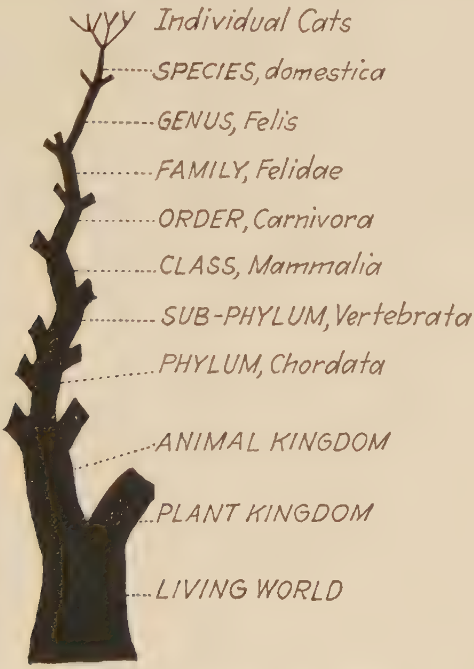


FIG. 4.—Diagram to show the tree-like form assumed by a natural system of classification, as illustrated by the classification of the house cat, *Felis domestica*.

Scheme of Classification. Species are arranged in groups of higher order called *genera*. A number of species constitute a *genus* in much the same way that a number of individuals make up a species. The characteristics which distinguish one genus from another are more deep-seated and fundamental than those that distinguish species. Related genera, in turn, are combined into *families*, families into *orders*, orders into *classes*, and classes

into *phyla*. The phylum, then, is the largest group in either the *plant* or *animal kingdom*. Each group is sometimes made up of subgroups, such as *subphylum*, *subclass*, etc.; and occasionally entirely new terms are introduced to meet the needs of classification. The custom of employing Latin or Greek derivatives in the technical naming of these groups is now universally followed and makes for clearness in identification.

Binomial System.—Every kind of animal and plant has a scientific name, consisting of the name of its genus, capitalized, followed by the specific name, in small letters. Thus, the name of the house cat is *Felis domestica;* a common species of frog (Leopard frog), *Rana pipiens;* man, *Homo sapiens*. This method of naming was formulated by Linnaeus and is known as the binomial system of nomenclature.

Animal Phyla.—The names of the principal animal phyla with examples of each are given below to serve as a general guide for convenience in referring to the larger subdivisions of the animal kingdom.

1. **Protozoa,** unicellular animals, mostly microscopic in size, amœba, paramœcium, malarial parasite.
2. **Porifera,** sponges.
3. **Cœlenterata,** hydra, jellyfish.
4. **Ctenophora,** sea walnut, comb jelly.
5. **Platyhelminthes,** flatworms, tapeworms.
6. **Nemathelminthes,** round or threadworms, ascaris.
7. **Rotifera,** rotifers.
8. **Molluscoidea,** brachiopods.
9. **Echinodermata,** star fish, sea urchins.
10. **Annelida,** segmented worms, earth worms.
11. **Arthropoda,** insects, crayfish, lobster, spider.
12. **Mollusca,** snail, clam, oyster.
13. **Chordata,** animals with a notochord.

    SUB-PHYLUM:

    1. **Enteropneusta,** Balanoglossus.
    2. **Tunicata,** sea squirt.
    3. **Cephalochorda,** lancelet.
    4. **Vertebrata,** animals with a vertebral column or backbone. Fishes, frogs, reptiles, birds, mammals.

References

For further reading the following list of references is suggested:

LE DANTEC, F.: "The Nature and Origin of Life," A. S. Barnes & Company, 1906.

LOCY, W. A.: "Biology and Its Makers," Holt & Company, 1915.

Loeb, J.: "Dynamics of Living Matter," pp. 1–52, The Macmillan Company, 1906.

Lull, R. S.: "Organic Evolution," pp. 1–47, The Macmillan Company, 1917.

Mathews, A. P.: "Physiological Chemistry," pp. 3–15, William Wood & Company, 1916.

Sharp: "Introduction to Cytology," pp. 1–16, McGraw-Hill Book Co., 1921.

Shull, LaRue and Ruthven: "Animal Biology," pp. 1–24, McGraw-Hill Book Co., 1924.

Wilson, E. B.: "The Cell in Development and Heredity," The Macmillan Company, 1925.

CHAPTER II

ADAPTATION

The general considerations dealt with in the preceding chapter outline some of the guiding principles that have played an important part in shaping the development of biology in the past, some knowledge of which is desirable in establishing a viewpoint for further pursuit of the subject. In undertaking the actual study of an animal, one might naturally begin by making observations in the animal's *natural habitat* with a view to ascertaining the significance of external features, such as *color, form, behavior,* etc., since an explanation of many such peculiarities is found to depend upon the conditions under which the animal lives. Every animal is adapted to its environment. Studies of this sort soon show, however, that adaptations are very deep-seated and are not confined merely to the exterior of the body, but extend to the internal organs as well. In fact, the more adaptations are studied the more one is impressed with the way in which they permeate the entire organization of an animal; which, of course, only emphasizes the probable importance of adaptation as a factor in the evolution of the many and diverse forms of animal and plant life. Some adaptations are primarily morphological in character and others physiological, but an attempt to classify on such a basis meets with difficulties, since function and structure are inseparably related and most adaptations have a functional significance.

It is common knowledge that every animal and plant is fitted to live under the conditions of life peculiar to each. Not only is each nicely adjusted to its individual sphere, but each exhibits ability, up to a certain point, to make readjustments to meet new conditions when they arise. The quality of *fitness* and the power to make new *adjustment* are both implied in the term *adaptation.*

The frog, for example, is an *amphibious* animal. Its legs with webbed feet enable it to move about in water or on land with almost equal facility. It takes oxygen into its body not

only by means of lungs but also through its skin. Its color makes it inconspicuous and thus affords protection from enemies. The female lays its eggs in the water, and the young on hatching are capable of living entirely in the water until sufficient time has elapsed for organs to develop to the point where the animals can live on land as well.

The frog also possesses the power of adjustment to new conditions. If water in which a frog is placed is gradually frozen into ice and as gradually thawed, the animal comes through the ordeal none the worse from the treatment. Frogs kept in a vivarium for laboratory use ordinarily refuse food, and as a result frequently go without food for months, sometimes a whole year. These facts show that the metabolic processes of the frog are capable of adjustment within wide limits of *temperature* and *food* supply. On the other hand, *moisture* in some degree is a prime necessity; and it frequently happens that when a frog is left overnight in a warm, dry room it is dead by morning, its body greatly shrunken in size, due to loss of moisture. Its adaptability to moisture has greater limitations than its power to meet temperature changes.

If muscles work against a powerful resistance they become larger after a time, and capable of doing more work. The production of *callosities* in the skin as a result of friction is an adaptive response to pressure stimulation. By gradually increasing the dosage, an animal will develop *immunity* to quantities of poison which in the beginning would have been fatal. Every habitual user of tobacco daily absorbs an amount of nicotine and other toxic substances that would produce serious if not fatal results if administered to an uninitiated individual.

Origin of Adaptations.—Adaptations have probably arisen from the response of *internal* protoplasmic factors to *environmental* stimuli, but long periods of time have been required to bring about the conditions found in living things today. In order to picture in its barest outlines how this result could be achieved, protoplasm must be regarded as a *plastic* substance that has been molded by environmental conditions. Thus, in a large animal, an alimentary canal is a fundamental requirement for digesting and absorbing solid food, and it is assumed that the alimentary canal was evolved to take advantage of the kind of food available, and not vice versa. In other words, environment was not made for the convenience of living things,

but, on the contrary, *living things have been compelled to meet the conditions of environment* at any given time, and to meet new conditions as the environment changed. *Environment* is used in a broad sense to include all conditions, animate and inanimate, external to the organism.

It is often said that man has become independent of his environment, but this, of course, is only partly true. The truer statement would be that man is more independent of his environment than other living things, thanks to his ability to profit by experience, a faculty that has been slowly acquired. Generally speaking, the difference between man and other animals is one of *degree* rather than of kind.

Significance of Adaptation.—Adaptations have been evolved in the course of continual struggle between organisms and the conditions of life. The problem which every living thing must solve in order to live and keep its race alive is the same for all, but the solution is achieved in many different ways. Briefly stated, the problem is as follows:

1. *Preservation of self*, which includes: Gaining sustenance from environment, and *protection of self* from destructive forces both animate and inanimate.

2. *Preservation of race*, by each organism producing its own kind in sufficient numbers to guarantee the continued existence of the race.

Adaptations are always related to one or more aspects of this fundamental problem. The study of biology is a study of adaptations.

The examples of adaptations, most of them morphological in character, chosen for illustration in the following paragraphs will perhaps convey some idea of the remarkable degree to which adaptive modifications may be carried, but the list is by no means exhaustive, since its primary purpose is to serve as an introduction to the subject.

Weapons.—*Claws*, *teeth* and *horns* are all familiar examples of defensive organs, some of which may also be useful in capturing food. An unusual weapon is the *sting* of the honeybee, *Apis mellifica*, which consists of a pair of barbed darts protected by a sheath when not in use. The real damage is caused not by the puncture, but by the action of the poisonous fluid injected into the wound from the poison sac attached to the sting. If the sting remains in the wound, the poison gland and the adjacent

organs in the tip of the bee's abdomen are torn out with the sting, and the bee loses its life. The effective value of the sting might be questioned, since its use frequently causes the death of the user, but this objection disappears when one understands that the activities of the members of a colony of bees center about the welfare of the colony rather than the individual—as a safe-

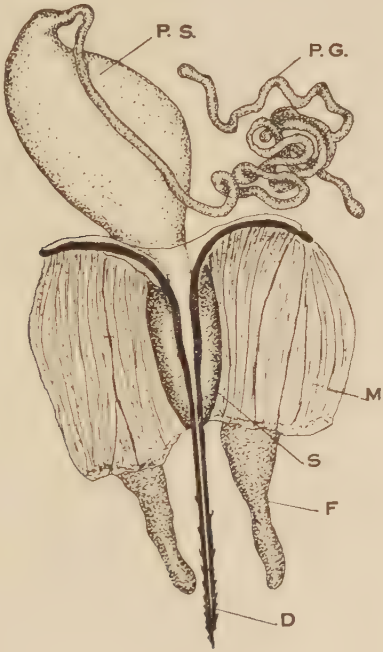


FIG. 5.—Sting of the honeybee, *Apis mellifica*, dissected. D, serrated darts; F, feelers provided with tactile sense organs; M, muscles, attached at the lower edge to the body wall, whose contractions force the darts into the wound; P.S., poison sac with a duct leading to the darts; P.G., poison gland; S, sheath into which the darts can be withdrawn.

guard against the destruction of the entire colony, the loss of a few individual lives is nothing.

As to its *origin*, it is known that the sting is really a modified *ovipositor*. The ovipositor is an organ located in the tip of the abdomen of the female of many insects and is used for boring holes in the ground and elsewhere where the eggs are deposited. Among bees the *queen* is the functional female, but, since she lays her eggs in wax cells prepared by *workers*, which are also females —but females incapable of laying eggs—there is no need for an

ovipositor. In both queen and worker the ovipositor is represented by the sting. The males or *drones*, naturally, have no sting.

Another extraordinary weapon is the *electric organ* of certain fishes, which is capable of producing an electrical current too weak, apparently, to be very effective in many cases, but strong enough in the electric skate (*Torpedo*) or the electric eel (*Gymnotus*) to be of value as a means of protection. The organ consists of modified muscle tissue arranged in a large number of plates, called *electroplaxes*, located, in the skate, at either side of the head, and, in the eel, on either side of the trunk. The arrangement of the tissue suggests a *voltaic pile*, consisting as it does of an electric layer enclosing a middle or striated layer, separated from adjacent layers by gelatinous layers. The discharge is under the control of the nervous system, the nervous stimuli entering by *motor* endings on the one side of each electroplax. The quantity of the discharge varies with the size of the organ and its state of fatigue. In order to understand this organ, it must be noted that in every animal the contraction of a muscle is always accompanied by minute electric discharges. In the electric fishes, on the other hand, muscles in certain parts of the body have been curiously modified to produce strong electric currents. The phenomenon which seems so inexplicable at first merely proves to be another case in which an organ has changed its function.

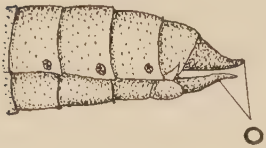


Fig. 6.—Abdomen of the grasshopper showing the ovipositor, o.

Protective Resemblance.—In many cases the general harmony between the coloration of an animal and its surroundings makes it difficult for the observer to see the animal, especially when it is not in motion. The gray-brown of the *ground-dwelling toad*, the brilliant green of the *tree-dwelling toad*, and the white color of the *polar bear*, the *arctic hare*, or the *arctic fox* are all examples of *protective coloration*. Green-colored birds abound in the tropics, but are rare in other zones. The *flounder* or *sole*, a bottom-feeding fish, is white underneath, but mottled on its upper surface, the color pattern of which can be changed to a certain extent to harmonize with the bottom. Among some animals, like the *ptarmigan*, *otter*, *northern fox*, and *varying hare*, the color pattern changes with the seasons, being white

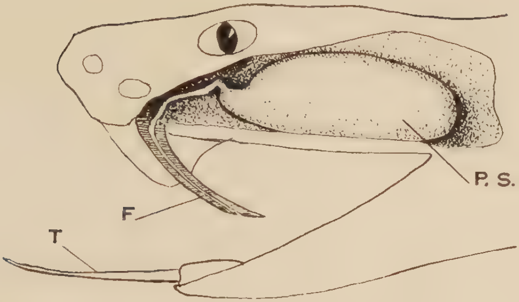


FIG. 7.—Head of the rattlesnake, based on a dissection to show the poison apparatus. F, hollow fang, shown in vertical section, is hinged above to the maxillary bone of the skull, so that it can be folded back when the mouth is closed; P.S., poison sac, a modified salivary gland, whose duct conveys the secretion to the fang; T, tongue, which is harmless and serves principally as a tactile sense organ. As in the bee, the damage or injury is caused by the highly toxic venom injected into the wound.

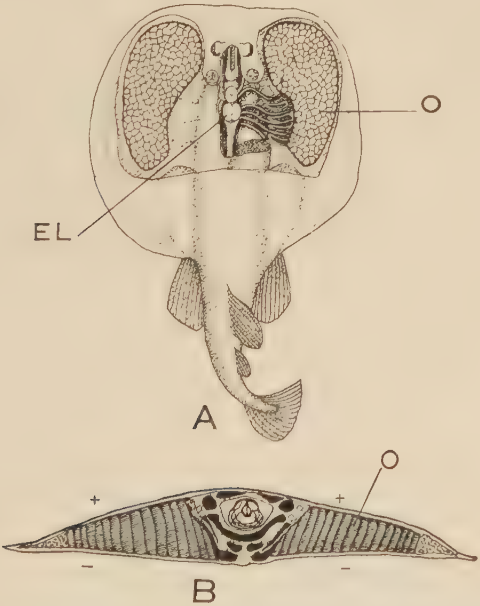


FIG. 8.—Electric organs of *Torpedo marmorata.* A, dorsal view of entire animal, the upper surface being partially dissected away to show the electric organs, O, and the brain with its electric lobes, EL, from which nerves pass to the electric organs. B, Transverse section through the entire body at the level of the electric lobes of the brain, showing the electric organs composed of flat discs, electroplaxes, arranged in vertical columns. The polarity of the current generated in the organ is indicated by plus and minus signs. (*Redrawn from Dahlgren, Carnegie Inst. Pub., after Fritsch.*)

in winter and varying shades of brown and gray during the rest of the year.

Among *birds* the male, as a rule, has far more gorgeous and, therefore, more conspicuous plumage than the female. The significance of the male color pattern is not altogether clear, but one can readily understand the importance of the inconspicuous, protective coloration of the female, since such protection is necessary during the breeding season when she is on the nest incubating eggs. The young of either sex are protectively colored to an equal degree until sexual maturity, when the adult type of plumage develops. Similar differences in lesser degree exist between the sexes of other forms.

FIG. 9.—*Kallima parallecta*, the Indian leaf-butterfly. A, at rest with its wings folded; B, with the wings spread.

Mimicry.—The protective value of coloration is greatly enhanced when the animal possesses, in addition, a bodily structure which closely resembles surrounding objects. This is called *mimicry*, of which the best examples are found among insects. Thus, the dead-leaf butterfly, *Kallima parallecta*, an Asiatic form, when at rest, with its wings folded over its body, looks remarkably like a dead leaf, not only in the brown color of

the under side of its wings, but in the reproduction there of every detail of the leaf structure—stalk, midrib, and veins. Even worm holes are reproduced. A common American insect, the walking stick, *Diapheromera femorata*, gets its name from its resemblance to a branched twig, its long greenish-gray body and its shaggy legs making it almost indistinguishable from a dry twig. In other cases the resemblance may be between two animals, a harmless or defenseless one deriving a certain amount of advantage from having a resemblance to a well protected one. Thus, bees and wasps which

Fig. 10.

Fig. 11.

Fig. 10.—*Phyllium*, the green leaf-insect, a South American form of a bright green color and a broad leaf-like body; an example of mimicry. (*From Jordan and Kellogg, Evolution and Animal Life, D. Appleton & Co. By permission.*)

Fig. 11.—The walking stick, *Diapheromera*, on a twig. (*From Jordan and Kellogg, Evolution and Animal Life, D. Appleton & Co. By permission.*)

are provided with dangerous weapons in the form of stings, are mimicked by a whole host of flies and moths. The common monarch butterfly, *Anosia plexippus*, is inedible, or at least distasteful to birds, while its imitator, the viceroy, *Basilarchia archippus* is edible. In these and other cases of mimicry the

Fig. 12.—The figure at the top is the inedible monarch butterfly, *Anosia plexippus*. The middle figure is the edible viceroy, *Basilarchia archippus*. The lowest figure is another member of the same genus, *Basilarchia*, to show the usual color pattern of the species of the genus. (*From Jordan and Kellogg, Evolution and Animal Life, D. Appleton & Co. By permission.*)

condition is not to be regarded as a conscious act on the part of the *imitator*. The steps by which the resemblance has been brought about are unknown, but their history is in all probability similar to that of all other adaptations to environment.

Warning Coloration.—Striking pigmentation is met with among poisonous or other noxious animals. The orange-and-black coloration of the bodies of *hornets* and *wasps* is a constant warning to enemies not to molest them. Likewise, the white stripes or spots on the otherwise black coat of the *skunk* is a warning to its enemies to keep beyond the range of its scent glands.

Warning adaptations are to be regarded as primarily for the protection and benefit of the possessor rather than its enemies. It is advantageous for the harmful animal to advertise its presence, because this warning relieves it of the necessity of inflicting punishment. One or two experiences probably teach a bird to disregard unpalatable insects, with the result that the latter as a whole are benefited, though some are killed. This interpretation is supported by experiments which show that hungry animals discriminate between palatable caterpillars and other varieties.

Signals.—To be able to signal seems to play a part in the protective adaptations of some animals. In the *Virginia deer* the underside of the tail and the adjacent parts of the body covered by the tail are white. When one of a herd becomes aware of danger and moves off, its tail invariably flies up like a signal flag and, by attracting the attention of the rest of the herd, acts as a warning to them. Similarly, the *antelope* has signal markings on the rump, consisting of white hairs which can be flashed by a spreading of the hairs. The white hair on the under side of the tail of the *rabbit*, which is so conspicuous when the animal is running, is supposed by some to serve as a beacon to the young to enable them to follow the parent and escape from danger.

Feint.—Some animals feign death when they are in danger of capture. The *orb-weaving spiders*, when touched, drop to the ground by a long thread that is spun during the fall. On the ground the spider draws up its legs and remains perfectly quiet as long as danger threatens. Many insects, especially *beetles*, have a similar habit of falling to the ground and remaining perfectly motionless for a time. The *opossum's* well-known antics of feigning death are probably of real value to it when attacked by an enemy that prefers to kill its prey, although, of

course, the ruse fails when man happens to be the enemy. The *partridge* and other birds during the breeding season simulate lameness in order to decoy hunters away from the nest of the young. When this has been accomplished or if its enemies get too close for comfort, the bird quits shamming and makes its escape by flight.

Animal Associations.—*Gregarious* animals like the *ungulates* (hoofed forms) herd together for safety, and not for obtaining food, since the large numbers brought together on a common feeding ground reduce the amount of food available. Such herds have *leaders*—a female for buffaloes, and a male for horses and other animals. Occasionally one finds two or more species of animals associated. Thus, herds of *elephants* have been seen associated with flocks of *white herons;* and a common herding of *zebra, ostrich,* and *gnu* is said to occur frequently. All domestic animals, except the cat, are gregarious in habit.

Worker. Queen. Drone.
FIG. 13.—Honeybee. × 2. (*From Phillips, U.S.D.A. Farmer's Bulletin* 447.)

Communalism.—Animal associations of a permanent character in which there is a well-marked division of labor, often accompanied by a physical differentiation of the individual members is termed communalism. The social organization of the bee or of the ant is a good example of this.

The *bee colony* is a unit, a compound organisn, in which all the activities of the individual members are directed toward the interest and the welfare of the colony. A typical colony is composed of a single *queen*, the only female capable of laying eggs, four or five hundred *drones* or males, and thousands of *workers* who are females with aborted reproductive organs and

therefore incapable of producing eggs. The function of the queen is to lay eggs, of the males to produce sperm for fertilizing the eggs, while to the workers fall the burden of caring for the entire colony, including rearing of the young, and the building and guarding of the nest. Colonial life of this sort is for the combined purposes of protection, food getting, and reproducing offspring.

Commensalism.—Animals of different species are often found associated for *mutual benefit.* The instance of the zebra, ostrich, and gnu has been already mentioned, but the association in other forms is such as to make the benefit rather one-sided and anything but mutual. Thus, the *remora,* or suckfish, by means of a large sucking disc on the top of its head attaches itself to sharks and other large fish, allowing itself to be carried about and leaving

FIG. 14.—*Remora,* the suckfish. The dorsal fin is modified into a sucking disc by which the fish attaches itself to a shark. (*After Jordan and Kellogg.*)

its anchorage only in order to share its host's food. The shark is not injured in any way by the remora, but neither is it benefited. Similarly, *barnacles* are found attached to whales and turtles, just as they are to stones and wood.

Symbiosis.—A somewhat more intimate form of commensalism from which there seems to result a *mutual exchange* of benefits to the associated organisms is known as symbiosis. A common example is the association of the *hermit crab* with *sea anemones* or *hydroid polyps,* which, by covering the crab's shell, form an effective disguise. In eating, the crab unavoidably allows fragments of food to escape and float upward, so that they can be captured by the anemones or polyps on the shell. Thus, each animal undoubtedly benefits by the association. When the shell becomes too small for the crab, it leaves it for another and it is interesting to note that if the new shell is not already provided with its commensal mates the crab proceeds to transplant some to its new abode. This fact has been verified experimentally and indicates that the association between crab and polyp is by no means accidental.

Symbiosis also exists between animals and plants. Thus, the common green hydra, *Hydra viridis,* owes its color to the

presence of microscopic green plants embedded in its cells. These plants use as food the carbon dioxide given off by the animal tissues, while they in turn give off oxygen, which is readily consumed by the animal. Similarly, certain *Protozoa* often contain numbers of unicellular plants between which and their hosts the same relationship probably exists. The alimentary canal of vertebrates always contains *bacteria* which seem to be not only harmless but actually beneficial to the host as aids to digestion and absorption of food. The bacteria, on the other hand, receive food and protection.

Fig. 15.—Hermit crab and sea anemones. Usually the gasteropod shell inhabited by the crab is completely covered by sea anemones, but only two of the latter are represented for the sake of clearness.

Parasitism.—The word parasitism is applied to the association of an animal or plant with another, in which one of them, the *parasite*, receives food and protection from the other, the *host*, without giving any benefit in return. The effect upon the host is usually detrimental but not often fatal, since the death of the host would be distinctly disadvantageous to the parasite, unless death occurs after the latter has completed its development to a point where the host is no longer needed. Thus, the human tapeworm, *Tænia saginata*, lives in the alimentary tract of man, attaching itself by means of suckers to the lining of the intestine and absorbing food through its body walls from the medium in which it lies. It occurs frequently and, though unpleasant, is not necessarily

serious in its results. More detailed accounts of life histories of common parasites are reserved for later pages.

Regeneration.—Many animals have the power to replace or regenerate new parts if the old ones are lost. If the common flatworm, *Planaria,* be cut transversely, the head end will regenerate a new tail and the tail end will regenerate a new head. If a *crab* loses a leg, a new one is regenerated. The same is true of the *cockroach* before the final molt. If one or more arms are torn from a *starfish,* they are replaced with new ones. Power of regenerating lost parts—which may be regarded as a protective adaptation—is common among lower organisms, many

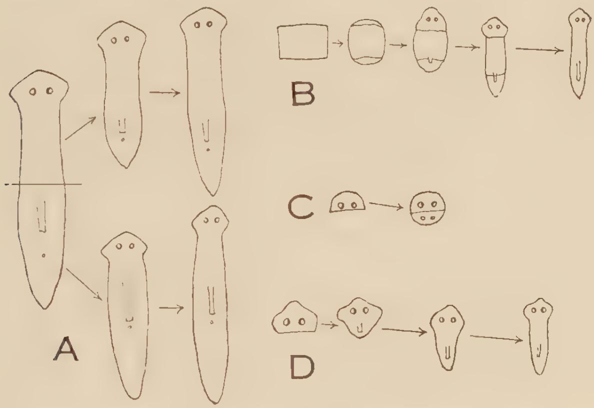


FIG. 16.—Regeneration in *Planaria.* A, regeneration of the anterior and posterior ends following transverse section. B, regeneration in piece taken from the middle. C, regeneration of new head on piece from head region. D, regeneration of a larger head piece. (*After Morgan.*)

of whom survive the loss of a considerable portion of the body. Among the higher groups, especially the vertebrates, regeneration of lost parts is rarer, and is mainly confined to *wound healing.* Wounds caused by injuries of any sort, unless promptly closed, seriously interrupt normal functional activity, not only because of the primary (*traumatic*) effect of the injury, but more particularly because the broken integument opens the way for invasions of bacteria or other parasites.

Immunity.—By slowly increasing the amount introduced into the body, immunity to certain poisons can be brought about gradually. Similarly, an animal can acquire an immunity to *bacterial diseases* by having the disease itself, in the course of which the

body manufactures *antibodies*, or *antitoxins*, which are substances that enable it to resist *reinfection* for some period afterward; or by having a mild form of the disease, such as follows *vaccination* against smallpox, in which a mild form of smallpox is produced as a result of the vaccination. The practice of giving antitoxin is based upon the fact that an animal, like the rabbit, guinea pig, or horse, inoculated with disease-producing bacteria reacts by producing a substance, antitoxin, which tends to kill the bacteria. *Serum*, the clear fluid obtained from clotted blood, taken from such an animal contains antitoxin, so that when such serum is injected into another animal it is capable of establishing immunity in the latter. Immunity reactions and regeneration are excellent examples of purely *physiological adaptation*.

Adaptations to Meet Conditions of Inanimate Nature.—The so-called *cold-blooded* animals have a body temperature but slightly higher than the surrounding medium. Fluctuations in body temperatures follow fluctuations in outside temperature, a condition described by the term *poikilothermous*. Thus some *fishes* can be gradually frozen in a block of ice and be recovered unharmed, provided the thawing is done gradually. In the frozen state the body temperature is practically the same as that of the ice. Such an animal requires no mechanism for maintaining a constant body temperature. In *warm-blooded* or *homothermous* animals like *birds* and *mammals*, the range of body temperature compatible with living is much more limited, and must be maintained in the neighborhood of 39° C. for birds and 37° C. for mammals, except in an animal during *hibernation*. Homothermous animals require an insulating covering to prevent loss of heat when the surrounding temperature is below that of the body; and some mechanism for preventing rise of temperature in the hot climates. *Feathers*, *heavy fur*, or *thick hide* constitute good protection against cold. Aquatic mammals, like the *whale*, living in the water, and practically devoid of hair, are provided with a thick layer of fat (*blubber*) beneath the skin. A covering of sufficient thickness will serve a dual purpose, so some animals, like the *elephant* or the *rhinoceros*, though living in the tropics, have skins thick enough to protect from the cold and shield from the sun. Among this type overheating is prevented by the evaporation of moisture from the inner surface of the lungs and by bathing in water. The thick hide, of course, also serves as a protection against

injury from other animals. In the temperate zones animals have heavy coats of hair in winter which are shed for lighter coats in summer. Man and some other animals are provided with *sweat glands* which excrete water and waste products on the surface of the body, the evaporation of the water cooling the body. These sweat glands are important in regulating the body temperature. Man also meets the problem by putting on and taking off clothing.

Hibernation.—Animals, like the *bear*, *groundhog* etc., spend the greater part of the winter months in a state of suspended animation in a burrow in the ground during which the body temperature may drop to 2° C. The bear goes into winter quarters plump and fat and comes out in the spring thin and scraggy. When the hibernating animal awakes, the rise in temperature is enormous and abrupt. According to Pembry, the temperature of the *dormouse* arose in one hour from 13.5 to 35.7° C., and that of the *bat* in fifteen minutes from 17 to 34° C. (quoted from Stewart).

Moisture.—The concentration of the body fluids must be maintained at a certain degree for metabolism to go on. If an undue amount of water is lost through the integument or in other ways, death ensues. *Aquatic* and *semiaquatic animals*, like *fishes* and *amphibians*, are adapted to a moist environment, and if placed in a dry atmosphere lose water very rapidly through the skin. In *terrestrial animals* such loss does not occur, owing to the difference in the nature of the integument, adapted as it is to a drier medium and, therefore, less permeable to the moisture, although a certain amount of moisture does escape through the skin. *Desert animals* show interesting adaptations for providing the body with the necessary amount of water. The stomach of the camel contains water reservoirs in the shape of small flask-shaped cavities, each having a constricted mouth. When the stomach is filled with water, the muscles relax automatically, allowing the water to enter the cavities. The water remaining in the general cavity of the stomach is absorbed. Later, as the demand for water arises, the liquid is released in small quantities from the reservoirs. This remarkable adaptation enables a mammal of large size to go without water for days. Many of the smaller desert forms of *mice* and *lizards* are said to obtain sufficient water for their needs from their food, so that it is not necessary for them to take water in the free state.

Pressure.—Animals are adapted to the conditions of atmospheric or hydrostatic pressure under which they live. *Deep-sea fishes*, when brought to the surface from depths of 10,000 to 16,000 feet, are unable to survive the transition. The tissues appear flaccid, as the sudden reduction in pressure causes the cells to expand to the point where they actually break down. A change due to atmospheric pressure occurs when a person accustomed to lower altitudes suffers from the lack of oxygen in the rarer atmospheres of a high mountain. In this case oxygen is not absorbed in large enough amounts to supply the needs of the body.

Adaptations for Race Preservation.—In many animals no such thing as *parental care* of the young exists. Marine forms, like the *starfish*, *sea urchin*, and many *fishes*, deposit the eggs in water, where they are fertilized, after which all responsibility ceases. The development of starfish is so rapid that in twenty-four hours it has advanced to the stage where free swimming larvae are produced which are fully able to care for themselves. In fishes developing outside of the body, the egg is provided with a quantity of *yolk* which serves as a source of nutrition until the young fish is able to shift for itself, but even here the rate of development is very rapid. Among other fishes and among amphibians the eggs are deposited with some pretense at concealment, so that they do not become too easy prey, but on the whole the parental supervision and protection is rather scanty. Naturally, an enormous number of eggs and embryos are destroyed, but since the rate of reproduction is so great—a cod is said to produce six million eggs—there is under ordinary conditions but little danger of the extermination of any given species. Most *birds* protect and feed their young as long as they are weak and unable to care for themselves. Bird nests are in most cases temporary homes, built primarily for the protection of the young, and therefore occupied only during the breeding season.

Among other animals the protection, care, and rearing of the young seems to be the principal business of life. The meticulous care which the *honeybee* bestows upon the young in all stages of development is an example. The food of the developing *larvæ* is not only collected but is partially digested by the workers before being administered to the young. The character of the food is changed to suit the change in requirements of the larva at different stages of its development. The care

and the guardianship exercised by the worker does not cease until the young reaches its fully developed condition when it is relinquished with a few final touches. The remarkable part of it all is that the progeny are not the offspring of the workers,

FIG. 17.—Black swamp-wallaby of Australia carrying young in the marsupium. (*From Shull, La Rue and Ruthven, Animal Biology.*)

but of the queen. Parental care is exercised only by the *foster parents.*

The actual time required for the development of *mammals* to the adult state is considerably longer than for other animals. In general, mammals that depend primarily upon speed for escape

from danger cannot have helpless or unprotected young, so that the young must be capable of rapid locomotion as soon as born, or be brought forth in some secluded spot. Thus, the young of the *ox* or *deer* are capable of running or walking shortly after birth. Of course, the young are dependent upon the mother's milk for food—as is the case with all mammals—but in times of danger they are capable of fleeing with the mother. In the somewhat unusual case of the *kangaroo,* the young are born in an extremely immature condition but are at once transferred into a large pouch formed by a fold of the skin of the abdomen in which they are carried. According to the observations of Hartman, in the case of the *opossum,* the newly born animal reaches the pouch by its own efforts. In the pouch the young grasps the nipple of the mammary gland, from which milk is forced into the mouth by mammary muscles, strangulation being prevented by the prolongation of the larynx into the nasopharynx. Even after the young kangaroo runs about, it often retreats to the pouch. *Rodents* and *carnivores* also bear their young in a relatively immature state of development. Newly born rabbits or kittens are blind and remain so for days, during which time they are dependent on the parent for both food and protection. In each case the young are brought forth in a secluded place.

The foregoing examples serve to illustrate, to a certain extent at least, the fact that, however complex or specialized the adaptation of structure to function, the condition is always bound up with the principal business of animals, namely, *self-preservation* and *race preservation.* Adaptations are fundamentally of the same nature, whether the animal under discussion be a man or a tapeworm. As has been said before, the problem is the same for all, but the solution has been reached in many different ways.

Non-adaptive Characters.—It is not likely that all coloration is adaptive. Thus, it is difficult to understand how the brilliant colors of many *marine fishes,* especially the deep-sea forms living at great depths where light is totally absent, can be of any particular benefit to the animal. Likewise, the beautiful colors of the shells of many *molluscs,* or the colors of *coral,* are apparently not adaptive.

It is also probably a fact that all structural peculiarities are not adaptive. It is not only conceivable, but undoubtedly true, that certain morphological features of *neutral,* or at least

questionable, value do develop, survive, and remain. Once adaptive features are recognized, there is a tendency on the part of the student to see adaptation in everything, but this, of course, is not necessarily the case. At the same time, it is hard to understand how any *non-adaptive character* can survive in an animal should it become a positive handicap to the animal in the struggle for existence. That many *apparently* non-adaptive characters do survive is perfectly clear from the fact that such characters are frequently used by systematists for purposes of classification because they are stable and permanent, and afford a ready means of differentiating species. It is well, therefore, to warn the student against a too enthusiastic attitude toward the idea of adaptation to prevent him from falling into the error of seeking an adaptive interpretation where it does not exist.

References

Dendy, A.: "Outlines of Evolutionary Biology," pp. 320–340, D. Appleton & Company, 1913.

Henderson, L. J.: "The Fitness of the Environment," The Macmillan Company, 1913.

Jordan, D. S. and Kellogg, V. L.: "Evolution and Animal Life," pp. 327–426, D. Appleton & Company, 1907.

Morgan, T. H.: "Evolution and Adaptation," Columbia University Press, 1903.

Symposium on Adaptation: Papers by M. M. Metcalf, B. E. Livingston, G. H. Parker, A. P. Mathews, and L. J. Henderson, *American Naturalist*, vol. 47, 1913.

CHAPTER III

ORGANOLOGY

An *organ* is a unit of the body having a definite form and structure adapted for performing a definite function. The different organs of an individual are interrelated and dependent one upon another in such a way that their combined activities, properly controlled, produce a smoothly working mechanism, wonderfully well adapted for the particular station in life which the animal happens to occupy. The animal body, therefore, is composed of a number of *organ units*, very precisely coordinated, each one playing a definite part in the activity of the whole. In much the same way the animal is also a unit of a higher order whose activities are coordinated with those of other forms of life, both animal and plant. The *physiological balance* maintained between different organisms is often as delicate as that between different organs of the individual.

The animal body, then, may be regarded as a machine which is capable of performing a number of functions. The primary functions are the same for all animals, but the visible structure of the machine and its size vary according to the position of the animal in the scale, that is, to its *station* in the scheme of life. Therefore, unicellular animals, the *Protozoa*, possessing as they do a much simpler structure than any of the higher groups whose bodies are composed of more than one cell, make a logical starting point for a discussion of types of organization.

Unicellular Organization.—Any protozoan would serve to illustrate how the conditions of life are met by an animal whose entire body is limited to a single cell. They are found practically everywhere—in water, in the air, and as parasites in the tissues of other animals. Most protozoans are invisible to the unaided eye, yet under the microscope they reveal a degree of organization that is amazing. Even in these primitive animals organs of a very simple character known as organelles are present, and these organs perform metabolic functions comparable to those of higher animals.

Amœba proteus is a common protozoan found creeping about on the mud at the bottom of ponds and on plants in the water. Under the microscope (its size varies from 127 to 340μ) the amœba appears as an irregular jelly-like mass of protoplasm, constantly changing its shape by projecting finger-like extensions

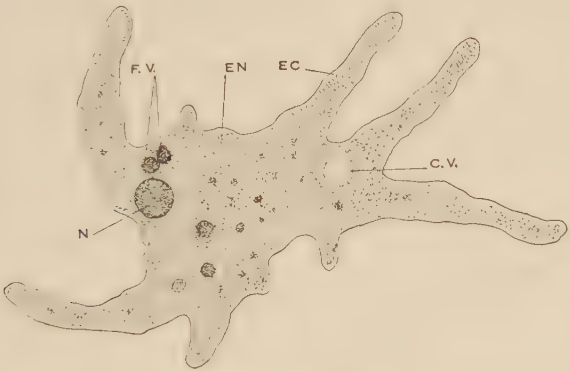


FIG. 18.—*Amœba proteus* with pseudopodia extended. EC, ectoplasm; EN, endoplasm; F.V., food-vacuole; C.V., contractile vacuole (expanded); N, nucleus.

of its body, known as *pseudopodia*, by means of which it moves about. One, sometimes two, *nuclei* are embedded in the cytoplasm but not unalterably fixed in position. The cytoplasm is differentiated into an inner portion called the *endosarc* or *endoplasm*, which contains the nucleus and has a coarse granular appearance due to embedded particles of various sizes, and a

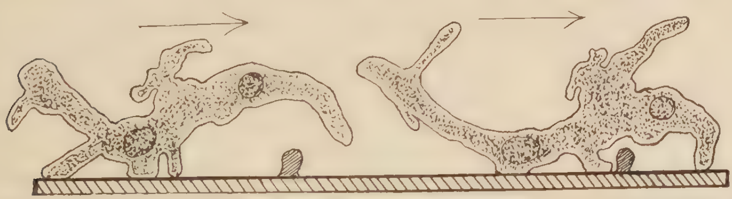


FIG. 19.—Side view of *Amœba proteus* moving over a solid substratum by attaching the extended pseudopodia and then drawing itself forward. (*Adapted from Dellinger, Jour. Exp. Zoöl.*)

narrow outer portion, the *ectosarc* or *ectoplasm*, which is soft and transparent, yet somewhat tougher and denser than the endoplasm. In the endoplasm the larger granules, surrounded by clear drops of fluid, are food particles in the process of digestion, the vesicles containing them being called *food vacuoles*. Near the surface of the body a large, spherical, *contractile vacuole*

may be seen, undergoing rythmical dilation and contraction. During contraction the vacuole disappears, its fluid contents being forced to the outside through the ectoplasm. It soon reappears as a small, clear spot, which grows rapidly to full size, when it again contracts and disappears. The contractile vacuole probably represents some primitive form of *circulatory* or *excretory* organ.

There is no special respiratory system, *respiratory changes* taking place at the surface of the body. There is neither nervous system nor sense organs, yet the animal reacts to stimuli of various sorts, showing that *irritability* and *contractility* are present as properties of the cell as a whole.

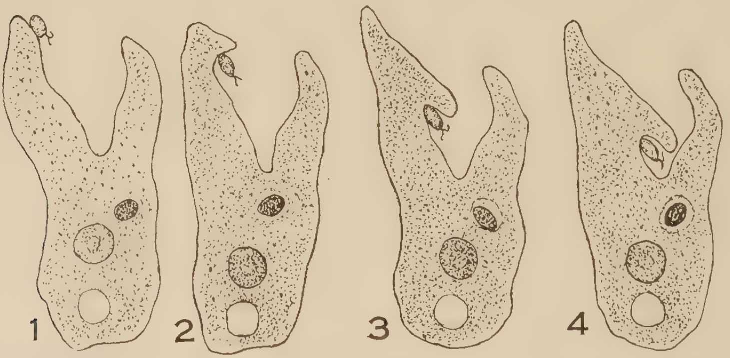


FIG. 20.—*Amœba proteus* capturing *Chilomonas para*, another protozoan, by means of its pseudopodia. Sketched at successive stages (*After Kepner and Taliaferro, Biol. Bull.*)

Amœba obtains its *food* by entangling prey with its pseudopodia and gradually engulfing the victim with whatever part of its body the capture is made. The action varies with conditions, showing that the animal, simple as it is, has some power of suiting action to requirement. The taking of food is not a haphazard process and the animal does not engulf everything it happens to meet, but is capable of distinguishing between food and grains of sand or other inedible objects. There is no permanent mouth or digestive tract—the so-called food vacuoles are temporary vesicles in which the food collects and in which digestion and absorption take place Undigested remains are cast out through the body wall.

Amœba is protected to a certain extent by its tough ectoplasm, but it often overcomes it enemies, if small enough, by

engulfing them, thus securing food and protection at one operation. Should the water of the pond in which it is living dry up, the amœba tides over the drought by secreting a thick protective covering called a *cyst*, in which it may remain enclosed indefinitely in a condition of *suspended animation* until revived by contact with water. While in the encysted condition, the animal may be blown about by the wind, or carried by animals, to a considerable distance from its original habitat.

Reproduction is a simple matter, being brought about by the cell dividing into two parts. In the process the nucleus divides first, and the two halves move away from each other; then the cytoplasm constricts into a bridge, which narrows and finally ruptures. The new cells resemble the parent cell, except that they are smaller in size. As soon as the new cells grow to full size, each of them in turn undergoes division. Thus, generation succeeds generation without the intervention of death, except by accident. There is really no distinction between parent and offspring, since the division products of any given cell are exactly alike. Reproduction in cases like this simply serves to make good the losses through accidental death.

The reproductive cycle of the amœba suggests that there is probably some *limit in size* beyond which the cell is unable to carry on metabolism. This limit in size is due, in part at least, to the relation of the surface of the cell to its volume or content. All metabolic change takes place at the surface of the cell, which means that food materials, including oxygen, are taken in, and waste or excretory products are given off, at the surface. The surface area, therefore, puts a definite limit to the amount of metabolism that can be performed by the cell. Since the volume of the sphere varies as the *cube* of the radius, and the area of the surface as the *square* of the radius, the volume of a growing sphere increases more rapidly in size than the surface. The same general relation holds for cells, even though some of them do depart rather widely from a strictly spherical shape. It is, therefore, undoubtedly true that in a growing cell the volume or content increases more rapidly than the all-important surface with the result that sooner or later a point is reached where growth must stop lest the surface area become insufficient to meet the metabolic requirements of the contents. When this limit is reached in amœba, the animal saves its life, *apparently*,

by undergoing division. Of course, the surface-volume relationship does not explain why the animal divides instead of ceasing to grow after reaching a definite size, but it is probably one of the reasons why the growth of the cell cannot *exceed* certain limits. Other factors are doubtless involved in causing cell division, but very little is known of these at the present time.

Amœba is merely one of a group of animals, the *Protozoa*, which differ from each other in structure and habits, but are alike in that they are all *unicellular organisms*, either free or colonial. They are called simple forms of animal life, and so they are, but their simplicity consists for the most part of minuteness in size. The chemistry and the physics of metabolism, irritability, conduction, or contractility of the Protozoa are just as complex and baffling as they are in the highest animals. The protozoan is as much a living thing in every sense of the term as is man. The difference between the lowest and the highest forms of life is not in fundamental characteristics of protoplasm, but in details that arise in connection with increase in size, such as *specialization* and *division of labor* among different cells.

Metazoan Organization.—The bodies of all the animals higher in the scale than Protozoa are composed of more than one cell. A beginning in multicellular organization is found even in the Protozoa, where colonial forms, like *Carchesium*, consist of a number of cells (individuals) attached to a common stalk, or, like *Volvox*, are made up of a sphere of cells united to each other by protoplasmic strands. Further, in Volvox any cell in the mass may become a germ cell, either an *ovum* or a *sperm cell*, both of which are essential for reproduction, the union of a sperm cell with an ovum being the starting point for the new colony. However, in these and other cases of colonial Protozoa, the cells making up the colony are really groups of *individual organisms*, each organism performing as amœba does, *all* the functions of an individual. In Metozoa on the other hand, there is a structural and a functional *specialization* in the cells of the body, making possible a physiological division of labor, which becomes more and more pronounced as the scale is ascended.

Tissues and Organs.—The cells of the metazoan may, therefore, be classified, according to structure and function, into tissues and organs. A *tissue* is a group of histologically similar cells, while a *metazoan organ* is a tissue complex having a definite form

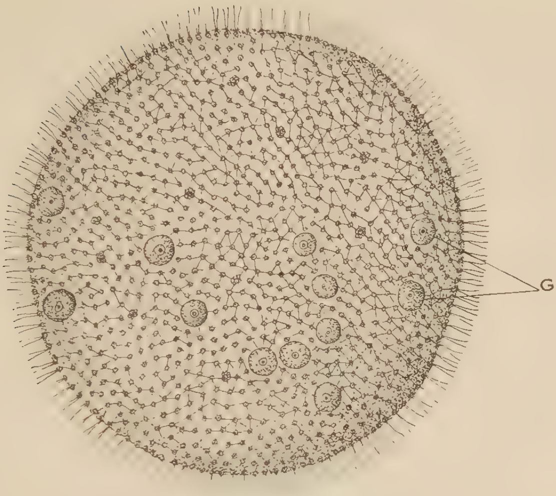


FIG. 21.—*Volvox perglobater*, containing developing germ cells, G. Volvox is made up of thousands of flagellated cells arranged in a gelatinous matrix in the form of a hollow sphere. The individual cells are connected by cytoplasmic extensions which give the sphere a reticulate appearance. Daughter-colonies develop within the cavity of the sphere.

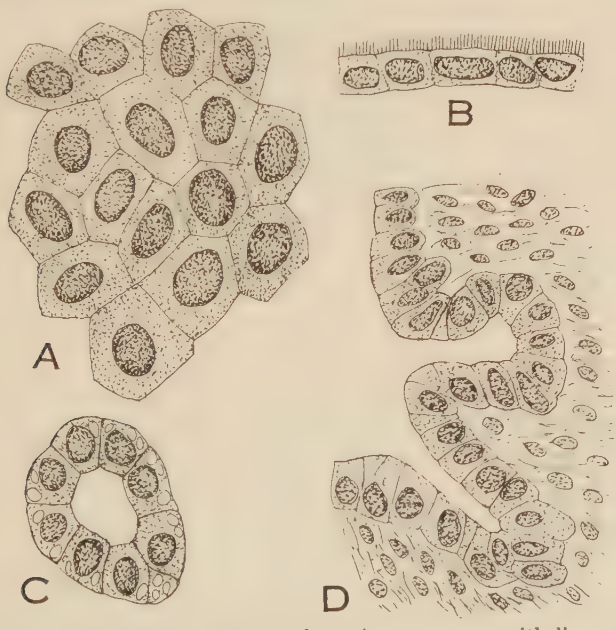


FIG. 22.—Tissues of larval salamander. A, squamous epithelium, skin; B, ciliated epithelium, pharynx; C, cubical epithelium, kidney tubule; D, glandular epithelium, intestine. $\times$ 300.

and structure for performing a special function. Every organ is made up of a *principal* tissue which is not found outside the organ, and *secondary tissues* common to all organs. Thus, the liver is composed principally of liver cells, but contains, in addition, blood vessels, nerves, connective tissue, etc. *Histology* deals with the study of the structure of tissues and organs. Tissues fall into four classes: epithelial, connective, muscular, and nervous tissue.

Epithelial Tissues.—An *epithelium* is composed of one or more layers of cells covering an outer surface, or lining a cavity. Epithelia are further characterized by the presence of only a slight amount of intercellular substance, known as *cement*

Fig. 23.—Stratified epithelium. Section of the epidermis of cat's foot showing fibrils bridging across the intercellular spaces. Cell bridges of this sort probably occur in all epithelia. (*From Schäfer, Textbook of Microscopic Anatomy, Longmans, Green & Co., after Kolossow. By permission.*)

substance, the function of which is to hold the cells together. On the other hand, intercellular bridges connecting cells are common. Epithelia are classified according to shape and arrangement as follows:

1. *Pavement* or *squamous* epithelium, composed of a single layer of flattened cells fitted together like flat blocks in a pavement. The outer layer of the *skin* of the frog, the lining of *blood vessels,* and the lining of the *body cavity* are examples.

2. *Cubical* epithelium has cube-shaped cells, such as occur in the tubules of the vertebrate *kidney.*

3. *Columnar* epithelium is made up of column-shaped cells, as, for example, the lining of the vertebrate *stomach* or *intestine*.

4. *Glandular* epithelium. Epithelial glands develop as ingrowths or *invaginations* of the surface covering, as in the *alimentary glands* of the lining of the *stomach* or *intestine*. These invaginations assume a variety of shapes, and glands are further classified according to shape. *Sweat glands* are a development of the skin, while in the stomach and intestine pit-like indentations of the lining form *digestive glands*.

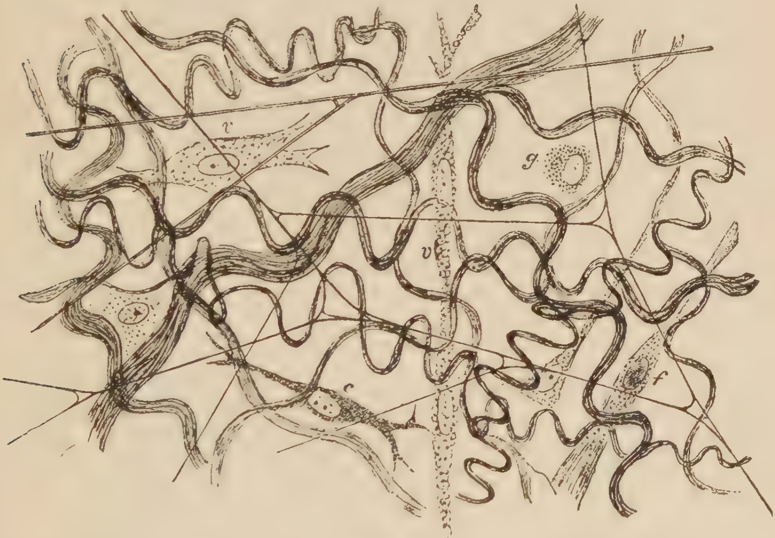


FIG. 24.—Subcutaneous areolar tissues from a rabbit as seen in a fresh preparation, under high magnification. The white fibers are in wavy bundles, the elastic fibers form an open network. Among the fibers are seen connective tissue cells of various sorts. *(From Schäfer, Textbook of Microscopic Anatomy, Longmans, Green & Co. By permission.)*

5. *Ciliated* epithelium consists of cells, usually columnar in form, provided with cilia on the free surface. Such cells occur in the *respiratory tract* of vertebrates, and in various parts of the body of many invertebrates.

6. *Stratified* epithelium is made up of superimposed layers of cells, as, for example, the *epidermis* or outer layer of the skin.

Connective Tissues.—The function of connective tissue is to support and connect other tissues, including: *areolar tissue*, which contains a large amount of white fibers and occurs in the subcutaneous region of mammals; *adipose tissue*, consisting of cells

filled with fat; *elastic tissue,* containing yellow, elastic fibers and occurring principally in the neck region of quadrupeds and between the vertebrae; *reticular tissue,* containing a dense network of white fibers, and found forming a fine framework for

FIG. 25.—Fat cells. *f.g.,* fat-globule distending a fat-cell; *n,* nucleus; *m,* membranous envelope of the fat-cell; *cr,* crystals in a fat-cell; *c,* capillary vessel; *v,* venule; *c.t.,* connective-tissue cell. *(From Schäfer, Textbook of Microscopic Anatomy, Longsman, Green & Co. By permission.)*

organs; *cartilage,* consisting of cells embedded in a matrix, translucent, firm, and at the same time elastic; *bone* in which cells are embedded in a rigid, hard, ground substance impregnated with salts of calcium, chiefly phosphate.

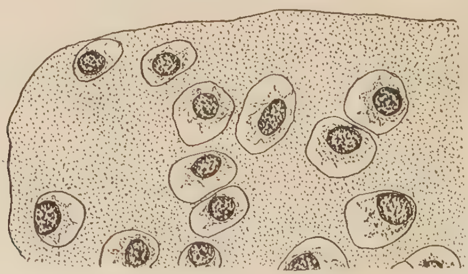


FIG. 26.—Cartilage, larval salamander. × 300.

Muscular Tissue.—A cell specialized for contraction is a muscle cell and groups of such cells constitute muscle tissue. In the higher groups of animals, three kinds of muscle are recognized: *voluntary striated* or *skeletal muscle* attached to the skeleton and causing, at will, general bodily movements; *involuntary striated*

or *cardiac muscle,* forming the musculature of the heart, the action of which is not under the control of the will; *unstriated* or

FIG. 27.—Cross section of compact bone from the shaft of the humerus showing the ground substance in white. The large black areas are occupied by blood vessels, the bone cells lying in the smaller spaces arranged in concentric circles. × 150. *(From Schäfer, Textbook of Microscopic Anatomy, Longmans, Green & Co., after Sharpy. By permission.)*

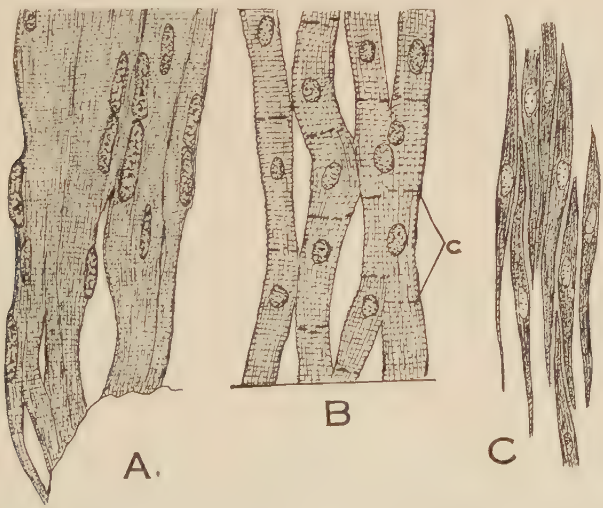


FIG. 28.—A, skeletal muscle, larval salamander; B, cardiac muscle fibers, mammal; C, smooth muscle cells, small intestine of frog; c, cement lines.

smooth muscle, occurring principally in the skin, the walls of the alimentary tract, and the blood vessels, and the action of which is likewise involuntary.

Muscle cells have a complex internal structure, only the general features of which can be considered here. Voluntary striated muscle is composed of bundles of long *fibers* which may be an inch in length in vertebrates. The fibers are really multinucleated cells forming a *syncytial* structure. The fibers, in turn, are made of bundles of *fibrillae* separated by clear *sarcoplasm*. A fibrilla

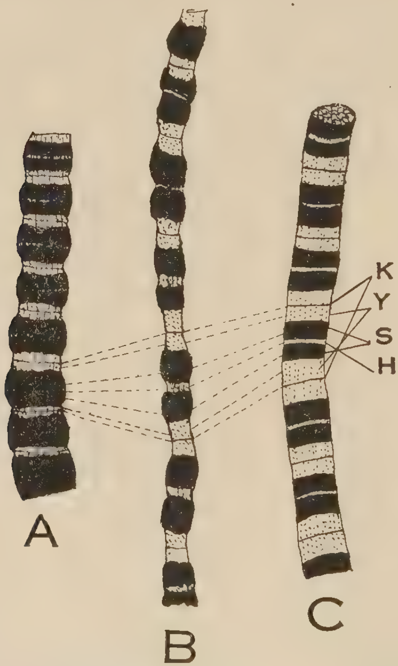


FIG. 29.—Fibrils (sarcostyles) of the wing muscle of the wasp. A, contracted fibril showing a reduction in the size of the hyaline zone and a corresponding increase in the sarcous substance; B, a stretched fibril with its sarcous elements separated at the line of Hensen; C, an uncontracted fibril. K, membrane of Krause forming the boundary of a sarcomere; Y, hyaline substance; S, sarcous element; H, Hensen's line. (*Adapted from Schäfer, Essentials of Histology, Longmans, Green & Co. By permission.*)

or sarcostyle is made up of *sarcomeres*, each of which consists of alternating light bands of *hyaline* substance and dark bands of *sarcous* substance giving muscle tissue when seen in longitudinal section a striated appearance. The sarcous substance is made up of short canals extending from the middle of the sarcous element to the edge of the hyaline substance. Such muscle is found in insects and as skeletal muscle in vertebrates.

The *cardiac muscle* of vertebrates is likewise striated, but the arrangement of the fibers in the form of a *branching syncytium* distinguishes it from skeletal muscle. In some vertebrates there is an approach to a more distinctly cellular structure, cell boundaries being indicated by irregular lines (*cement lines*).

Smooth muscle is composed of spindle-shaped cells, each containing a single nucleus. The cytoplasm contains longitudinal fibrils, but these lack striations. Such muscle is capable of only slow, sometimes rhythmical, contraction, such as characterizes the muscular movements in the cells of the alimentary tract and the blood vessels.

Nervous Tissue.—This tissue is adapted for receiving and conducting stimuli and forms the bulk of the nervous system. Typically, a nerve cell or *neuron* consists of a *cell body* provided with one or more *dendrons* or *dendrites*, and usually a simple *axon*, or *neurite*. The neuron forms the *unit* in the nervous system. There is, however, a bewildering variety of neuron patterns, so that it is difficult to describe the form of any single neuron as typical. The important part played by the nervous system as a *correlating* mechanism brings it into contact with all parts of the body, necessitating a variety of end organs peripherally and complicated connecting pathways in the central nervous system. A further consideration of the nervous system is taken up in a later chapter.

Organs.—The tissues are grouped in organs, each of which performs a certain function, or sometimes two or more functions, in the body economy. Each organ, in addition to peculiarities in size and shape, is characterized by a definite histological structure. In other words, structural and functional differentiation go on hand in hand, so that it is possible in many cases to correlate functional activity with histological characteristic and vice versa. In the following classification the names of the various organ systems have an obvious functional significance, yet these organs display just as pronounced structural characteristics. The organs of protozoans are differentiated regions in parts of a single cell, while those of metazoans are differentiated cell aggregates in different parts of a multicellular body.

Organ systems are usually classified as follows:

Integumentary, forming the outer protective covering of the body.

Skeletal, for support and protection.

Muscular, for the movement of the body as a whole or in part.

Fig. 30.—A nerve cell from the cerebral cortex. *a*, basal dendrons; *b*, apical dendron; *c*, collaterals of axon; *e*, axon; *p*, apical dendrons ending in branches near the surface of the brain. (*From Schäfer, Textbook of Microscopic Anatomy, Longmans, Green & Co., after Cajal. By permission.*)

Digestive, for the digestion and absorption of food.

Respiratory, for obtaining gaseous oxygen from the air or water, and giving off carbon dioxide.

Circulatory, for distributing food material absorbed from the alimentary canal, and oxygen; and collecting waste products from the tissues.

Excretory, for removing waste products from the tissues or circulatory fluid.

Nervous, for receiving stimuli from the outside and correlating the different activities of the body.

Reproductive, for producing offspring.

Endocrine glands, glands like the *thyroid*, *adrenal*, *pituitary* etc., each of which produces an *internal secretion*, which is circulated by the blood and produces specific effects in different parts of the body.

In the following chapters these organ systems are discussed in the order given above.

References

Böhm, A. A., von Davidoff, M., and Huber, G. C.: "Textbook of Histology," W. B. Saunders & Company, 1909.

Lewis, F. T.: Stöhr's "Textbook of Histology," P. Blakiston's Son & Company, 1910.

Schäfer, E. A. S.: "Essentials of Histology," Lea & Febiger, 1912.

CHAPTER IV

INTEGUMENT, SKELETON AND MUSCULATURE

The *integument*, the *skeleton*, and the *musculature* are closely associated both topographically and functionally, especially in the *invertebrates* (animals without a backbone). In many of the latter the integument and the skeleton are one and the same structure, to which the body muscles are attached. Among the *vertebrates* the relations are somewhat different, the skeleton having an internal location with reference to both skin and muscle. The skeleton, whether internal or external, provides support and protection for the soft parts, and bodily movements are brought about by the muscles moving portions of the skeletal framework. It is natural, therefore, that there should be a close relationship between muscle and skeleton, and in some cases the integument.

Integument.—The integument is the covering of the body and its function is primarily to afford protection to the internal organs; but the integument also contains *nervous elements* or *sense organs*, which give the animal responses to its environment. The entire nervous system, as a matter of fact, has its origin in the primitive outer layer of the body called the *ectoderm*. That this should be the case is not surprising when it is pointed out that the outside of the body is the part that is exposed to external stimuli of various kinds, a condition which brought about gradually a specialization of function in certain ectodermal cells, making them nerve cells. All the evidence points to an evolution of nervous tissue from ectoderm, and this is further borne out by the ectodermal origin of the nervous system in the *embryonic development* of the individual. A consideration of the nervous derivatives of the ectoderm is dealt with in later pages, under the head of the nervous system. At this point only the non-nervous features of the integument will be considered.

Invertebrate Integument.—In the *invertebrates* the integument consists of an outer epithelium, one cell layer in thickness, called the *epidermis*, and a greater or less amount of underlying

connective tissue of the areolar type. The epidermis, which represents the fully developed ectoderm of the embryo after the nervous system has separated from it, is rarely naked, but is covered by a hard, non-cellular layer, the *cutis* or *cuticle*, which

FIG. 31.—Portion of the new integument of a lobster, *Homarus* as seen in section. The cuticle is shown above in stratified layers. *conn.t.nu.*, connective-tissue nucleus; *bl.c.*, blood cells; *musc.c.*, muscles cells. (*From Dahlgren and Kepner, "Principles of Animal Histology," The Macmillan Co. By Permission.*)

is a secretion product of the epidermal cells. Thus, in the insects the cutis covering the outside of the body consists of an organic substance known as *chitin*, which not only serves as protective armor, but also gives support to the organs of the body. It

constitutes an *exoskeleton.* Chitin is not only hard, but resists to a remarkable degree the action of acids and alkalis. In other forms, like the *oyster, clam,* or *lobster,* the epidermal secretion contains a higher percentage of inorganic constituents, principally lime salts, which increases the hardness and rigidity of the external covering. In the *starfish, sea urchin,* and related animals, the hard body covering is due to a deposition of calcium salts in the subepidermal tissue. In the *lobster* and many other invertebrates, the cuticle is shed as a whole from time to time until full growth is attained. The process of shedding or molting is known as *ecdysis.*

Vertebrate Integument.—In all *vertebrates* the integument consists of two well-developed layers, the outer *epidermis* and the underlying *corium* or *derma.* At least two regions can be distinguished in the epidermis; the outer or *stratum corneum,* and the inner or *Malpighian layer.* New cells are constantly being formed in the *stratum germinativum* of the Malpighian layer whence they are gradually pushed to the outside to form the corneum. As they pass outward, they gradually become thin and flattened, until on the very outside they have the appearance of dried, dead flakes. They are constantly being rubbed off and lost, either piecemeal, or in entire sheets, as when the *snake* sloughs its skin.

The *Malpighian layer* gives rise to glands, of which common examples are the mammary *glands* and sweat *glands.* The sensory epithelium of the nose and the inner ear represent modified cells of this layer. Modifications of the stratum corneum result in the formation of *scales* (reptiles), *feathers, hair, nails, claws, horns, hoofs,* etc.

The *corium* consists largely of fibrous connective tissue, some elastic tissue, blood vessels, nerves, smooth muscle fibers, etc. *Leather,* the tanned hide of animals, is composed almost entirely of corium. *Ossifications* in the corium result in the formation of such structures as the *scales* of fishes, the bony plates forming the *plastron* and *carapace* of the turtle, the hard shell of the *armadillo,* etc.

Skeleton.—The hard parts resulting from the modifications of the integument constitute what is called the *exoskeleton.* It is the type of the skeleton found in invertebrates. While an exoskeleton in the form of bony plates is developed to a certain extent in the skin of such vertebrates as fishes, reptiles, armadillos

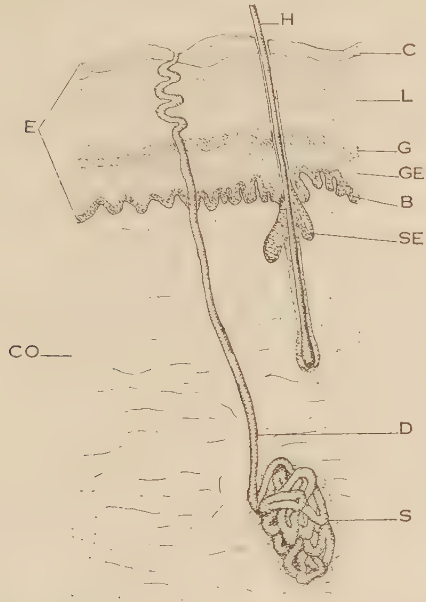


FIG. 32.—Vertical section of human skin, semidiagrammatic. B, basa layer of epidermis; C, stratum corneum, the outer layer of epidermis; CO, corium; D, duct of sweat gland; E, epidermis; G, stratum granulosum; GE, stratum germinativum; H, hair; L, stratum lucidum; S, sweat gland; SE, sebaceous gland, opening into hair-follicle.

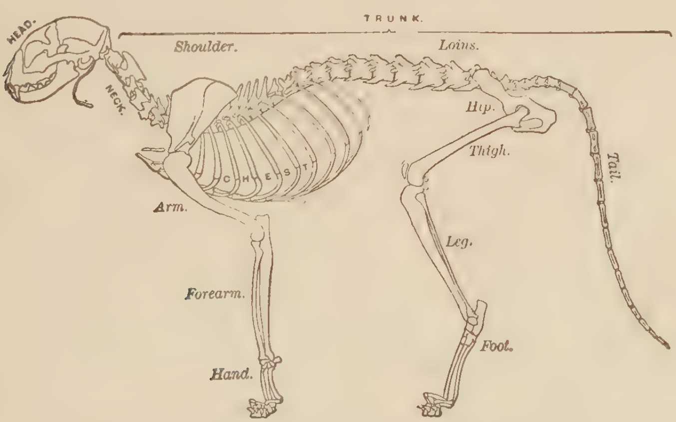


FIG. 33.—Regions of the vertebrate skeleton (cat). (*From Jayne, Mammalian Anatomy, J. B. Lippincott & Co. By permission.*)

etc., there is always present an *endoskeleton*, so called from the fact that it provides an internal framework to support and protect the body. The endoskeleton, except in the cartilaginous fishes, is composed of bone. The principal regions of the vertebrate skeleton are as follows:

1. *Axial skeleton*, which includes: *Skull and Vertebral column* or *backbone*.

2. *Appendicular skeleton*, which includes: *Pectoral* and *pelvic girdles*, and *Appendages*, arms and legs (Fig. 33).

Skull.—The skull consists of two regions, the *cranium*, which encloses and protects the brain, and the *visceral skeleton*, forming the skeleton of the face.

Vertebral Column.—The vertebral column is the longitudinal skeletal axis behind the head. It encloses and protects the *spinal cord* and supplies points of attachment for many important muscles of the body. Its flexibility is due to the fact that it is made up of a series of similar elements called *vertebrae* bound together by muscle and connective tissue. A typical vertebra consists of the following parts: the *centrum*, a solid part lying ventral to the spinal cord; the *neural arch*, arising dorsally from each side of the centrum, and enclosing the spinal cord; the *neural spine*, at the apex of the arch; the *hemal arch* (present only in fishes), extending from the ventral side of the centrum, and enclosing the blood vessels of the tail. In the higher forms articular processes, *zygapophyses*, occur, two at the anterior end and two at the posterior end of each vertebra at the base of the neural arch. *Transverse processes* extend laterally at the level of the centrum. In forms having *true ribs* (reptiles, birds, and mammals) a slightly dorsal *diapophysis* and a ventral *parapophysis* arise from the sides of the centrum, to provide articulating surfaces for the ribs (Figs. 34, 35).

The following regions are present in the vertebral column of the higher vertebrates: (1) the *cervical* or neck region, characterized by a reduction in the size of ribs, or their complete absence; (2) the *thoracic* region, which has ribs; (3) the *lumbar* region, without ribs; (4) the *sacral* region, composed of several vertebrae *ankylosed* (fused) to the pelvic girdle; and (5) the *caudal*, or tail region.

In the lowest vertebrates (*Cyclostomata*) there is a rudimentary vertebral column with poorly developed neural arches. The centra of the vertebrae are absent and in their place is a long,

unsegmented cylindrical rod, the *notochord*, which serves as the body axis. In fishes, vertebrae are present but the notochord persists, extending through the centra as a thin thread, and enlarged between the concave ends of the centra, so that if one were to remove the notochord completely it would have the form of a string of beads. In vertebrates above the fishes, the notochord

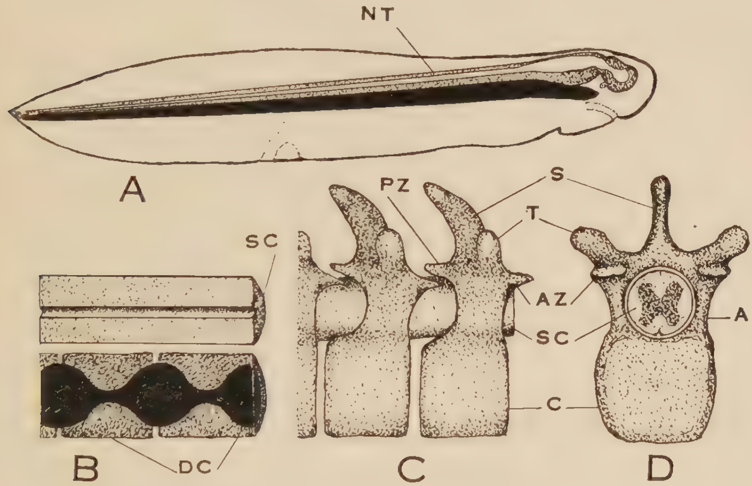


FIG. 34.—A, the notochord (in solid black) as seen in a longitudinal section of the larval salamander in which it represents the axial skeleton. The neural tube (NT) lying above consists of the brain and spinal cord. B, diagram of a median view of the spinal cord (SC) and developing centra (DC) split lengthwise. The notochord (in black) is partially replaced by the developing centra which gives it a beaded appearance that remains a permanent condition in fishes. C, a diagrammatic side-view of two completely developed vertebrae of a mammal, showing the intervertral foramina through which nerves and blood vessels pass. The nerves and blood vessels are omitted in the drawing. D, vertebra from the anterior side with the spinal cord shown in section in the vertebral canal. A, neural arch; C, centrum; S, neural spine; SC, spinal cord; T, transverse process; AZ, anterior zygapophysis; PZ, posterior zygapophysis.

becomes less and less prominent in the adult, until in mammals it is absent altogether. It is, however, present in the embryo of all vertebrates, being replaced in varying degrees by the centra of the vertebrae. The notochord represents the primitive, vertebrate *body axis*, which in higher forms is replaced by the vertebral column.

Ribs.—In the higher vertebrates, the ribs of the thoracic region are called true or pleural ribs, as distinguished from the *hemal*

ribs of fishes, which lie more ventrally. Each pleural rib has two heads, a *capitular head,* which articulates with the parapophysis of the vertebra, and a *tubercular head,* which articulates with the diapophysis. Ventrally, the ribs are attached by flexible cartilage to the sternum.

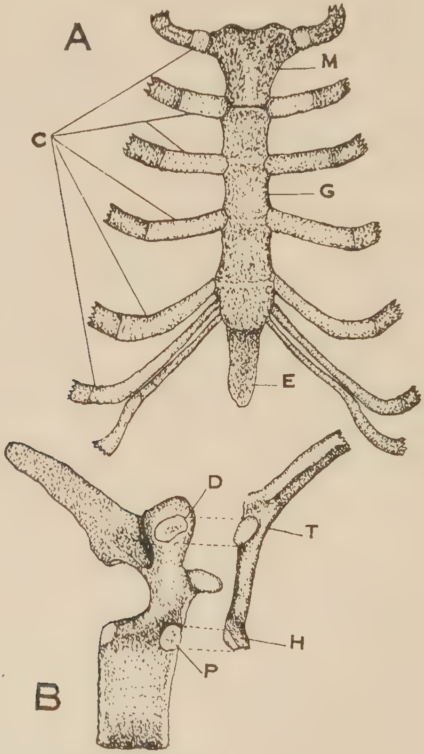


FIG. 35.—A, sternum of man showing the manner in which the ribs are attached by costal cartilages, C. E, ensiform process; G, gladiolus or body; M, manubrium. B, view of a thoracic vertebra from the right side with the dorsal end of the corresponding rib rotated so as to show its posterior aspect and the manner in which it articulates with the vertebra. D, diapophysis; H, capitular head of rib; T, tubercular head of rib.

Sternum.—This includes skeletal parts on the ventral side of the body that are closely related to the shoulder girdle and except in amphibia, with the ribs. In man it consists of three parts: the *manubrium,* anteriorly; the *gladiolus,* medially; and the *xiphoid* or *ensiform process,* posteriorly.

The connections of the ribs with the vertebral column dorsally, and with the sternum ventrally, permit changes in the size of the thoracic cavity during *respiration*. In the frog the ribs are short processes firmly attached to the vertebrae and not extending to the sternum. The frog's lungs are filled and emptied by raising and lowering the floor of the mouth.

Paired Appendages.—These do not articulate directly with the vertebral column, but with structures known as *girdles*, the

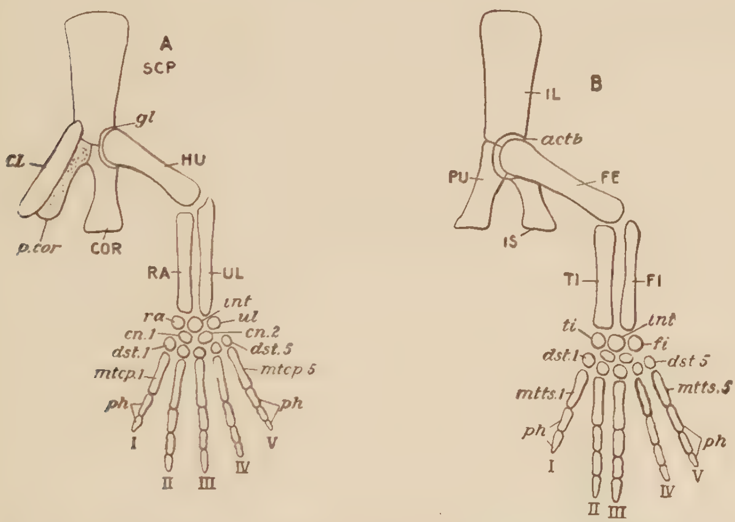


FIG. 36.—Diagram of generalized fore (A) and hind (B) limbs with limb girdles. *actb*, acetabulum; *CL*, clavicle; *cn.* 1, *cn.* 2, centralia; *COR*, coracoid; *dst.*1–5, distal row of carpals and tarsals; *FE*, femur; *FI*, fibula; *fi*, fibulare; *gl*, glenoid fossa; *I-V*, digits; *IL*, ilium; *int*, intermedium; *IS*, ischium; *mtcp.*1–5, metacarpals; *mtts.*1–5, metatarsals; *ph*, phalanges; *p.cor*, precoracoid; *PU*, pubis; *RA*, radius; *ra*, radiale; *SCP*, scapula; *TI*, tibia; *ti*, tibiale; *UL*, ulna; *ul*, ulnare. (*From Parker and Haswell, Textbook of Zoology, copyright, The Macmillan Co. By permission.*)

anterior appendages being attached to the *pectoral* or *shoulder girdle*, and the posterior appendages to the *pelvic girdle*. A beginning in the development of the girdles is indicated in fishes by the presence of cartilaginous or bony U-shaped structures to which the paired fins are attached, two to each girdle. In the frog the pectral girdle consists of four elements on each side of the shoulder, which, with the sternum below, form a bony semicircle. The *clavicle* is on the ventral side anteriorly, extending

from the shoulder joint to the sternum. Posterior to this is the *coracoid*, also extending from the shoulder to the sternum. Extending dorsally and medially from the shoulder is the *scapula*, which has as its continuation the cartilaginous *suprascapula*. The same elements are present in man, but with modifications. Thus, while the clavicle and scapula are well developed and occupy the same relative positions as in the frog, the suprascapula is absent and the coracoid is reduced to the small *coracoid process* of the scapula. The pectoral girdle is in all cases held in place by ligaments and muscles, and does not articulate with the vertebral column.

The pelvic girdle is much like the pectoral girdle, with which it may be compared part for part. Thus, the *pubis* is on the ventral side in the same relative position as the clavicle; the *ischium*, lying posteriorly to the pubis, corresponds to the coracoid; and the *ilium* extends dorsally to the scapula. However, the pelvic girdle differs from the pectoral girdle in its relation to the axial skeleton in all forms above the fishes. In fishes, both girdles are free of the vertebral column, but in the higher groups the pelvic girdle is firmly united to the sacrum on each side by a *sacroiliac* ankylosis, a fusion of the sacrum and ilium. This, together with the fact that the ischium and the pubis meet in the midventral line, makes the pelvis a firm, rigid structure. This is especially necessary in *bipeds* like man, where the entire weight of the trunk rests upon the pelvis. Further, the three elements of the pelvis, though separate in the embryo, are fused in the adult into a single bone, the *os innominatum*.

Paired appendages are present in all fishes, in the form of an anterior and a posterior pair of *fins*. The fin is a relatively simple structure, functioning as an oar or paddle in driving the fish through the water or in enabling it to maintain its balance. The skeleton consists of cartilaginous or bony rods which support a thin tough membrane. Except for differences in detail and some cases of special adaptation, it shows considerable uniformity in structure in different fishes, all of which is undoubtedly due to the uniform nature of the medium, water, in which fishes live. On the other hand, the paired appendages of vertebrates above fishes show a much greater variety in form and structure; but at the same time, the arm and leg of the tetrapod or biped, whether it be horse, bird, or man, are merely special modifications of a single type of limb. The arrangement and number of

elements present in the skeleton of the typical vertebrate fore and hindlimb are as follows:

Fore Limb		Hind Limb	
Upper arm....	*Humerus*	Thigh...........	*Femur*
Fore arm.....	*Radius Ulna*	Shank...........	*Tibula Fibula*
Wrist.........	*Carpal bones* (10)	Ankle...........	*Tarsal bones* (10)
Palm.........	*Metacarpal bones* (5)	Instep...........	*Metatarsal bones* (5)
Fingers.......	*Digits* (5)	Toes............	*Digits* (5)

Joints.—Between the different parts of the limb, joints make possible a range of movements entirely unknown in fishes. The *humerus* articulates at the shoulder with the scapula, clavicle, and coracoid (if present); while the head of the *femur* fits into a deep circular socket, the *acetabulum,* formed at the point of junction of the pubic, ischium, and ilium. At the distal end of the humerus is the *elbow* joint; at the distal end of the femur is the *knee.* The presence of two bones in the fore arm, the *radius* in front and the *ulna* behind, permits rotary movements of the hand, the distal end of the radius being capable of rotating through a considerable arc about the end of the ulna. A similar but more limited movement is possible in the foot. The knee cap, or *patella*, is an ossification in the tendon of the muscle passing from the thigh to the tibula. The number of *carpal* or *tarsal* bones varies in different animals owing to fusion or loss. Thus, in the frog there are six carpals and four tarsals; and in man seven carpals and eight tarsals. In the same way, the number of elements in the palm or sole, and the number of digits, may be reduced from five to four, three, or even one.

The vertebrate limbs, like the paired fins of fishes, are primarily *organs of locomotion.* They exist in their least modified form in *salamanders*, where, aside from swimming, they are used for crawling or running—simple methods of locomotion—over a solid substratum. The primitive terrestrial foot is five-toed and *plantigrade*, the entire sole or palm resting on the ground; but departures from this primitive state are numerous. For example, the horse, an *unguligrade* animal especially adapted for running, has but a single large toe on each foot, which corresponds to the middle toe of the five-toed type; the remaining digits have been sacrificed in the development of the single large one. Further, the *hoof*, which is the only part of the foot touching the ground, is the nail of the single remaining toe. In an animal like the dog or cat, there are five toes on the forefoot and four on the hind,

and in walking only the toes touch the ground, a condition known as *digitigrade*. In bears, on the other hand, the primitive five-toed and plantigrade foot is found; the same is true of man.

The *wing* of the bird is adapted for flying and shows even greater modifications. The carpal bones are greatly reduced by fusion, while the metacarpals and digits are modified and reduced in number to three, corresponding to the second, third, and fourth of the primitive type. The skeleton of the leg also is considerably modified. Thus, as a result of fusion between the proximal tarsals and the tibula (the fibula is much reduced) a *tibiotarsal* bone is formed, and from a fusion between the distal tarsals and the metatarsals, a *tarsomatatarsus;* as a result of which the ankle joint is formed by an articulation between these two bones. The number of toes varies from two to four, rarely five.

Musculature.—Muscle is the contractile tissue of the metazoan and causes movements of the body as a whole or in part. The arrangement and disposition of the body or skeletal muscle is closely related to the nature of the skeleton. In an animal without a hard skeleton, like the earthworm, the muscle tissue is arranged in the form of a *dermomuscular tunic*, composed of circular and longitudinal muscle fibers lying beneath the skin to which it is attached. While the general location of the musculature is the same in other invertebrates, in cases where a well-developed exoskeleton occurs, as, for example, in insects, the muscle tissue is arranged in groups of fibers, each group constituting a single *muscle* which may contract singly or in conjunction with other muscles.

In *fishes* the body musculature is arranged in thick V-shaped segments on either side of the body. These muscles are the principal organs of locomotion. The act of swimming results from the body being thrown into a series of reversed curves, beginning at the head and passing along to the tail. The unpaired median fins and the tail increase the amount of surface with which the fish *pushes* against the water. The paired fins act as balancers and also aid directly in moving the body.

In higher vertebrates the *skeletal muscle* consists of groups of distinct muscles attached to the skeleton either directly or by means of tendons. The *origin* of a muscle is the end attached to a relatively immovable part while the *insertion* is the opposite end. A muscle which bends one part upon another, as the leg upon the thigh, is a *flexor;* one that straightens out a part,

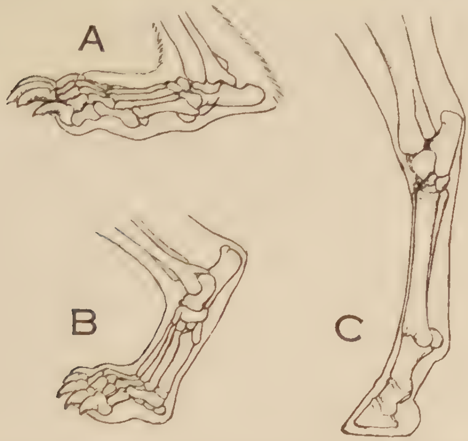


FIG. 37.—Foot postures. A, plantigrade, bear; B, digitigrade, hyena; C, ungulugrade, horse. (*A and B, after Lull, Organic Evolution, after Pander and D'Alton.*)

FIG. 38.—Skeleton of trunk and appendages of domestic fowl. 1, cervical rib; 2, ilium; 3, ischium; 4, pubis; 5, pygostyle; 6, ilio-sciatic foramen; 7, uncinate process; of thoracic rib; 8, humerus; 9, ulna; 10, radius; 11, ulnar carpal; 12, metacarpal of ulnar digit; 13, coracoid; 14, sternum; 15, metasternum; 16, hypocleidium; 17, clavicle; 18, femur; 19, fibula; 20, tibio-tarsus; 21, tarso-metatarsus; 22, metatarsus of first digit. I. II, III, IV, V, digits. The digits of the forelimb should be labeled II, III and IV instead of III, IV and V respectively.

an *extensor*. An *adductor* muscle pulls a part toward the midline; an *abductor* pulls it away from the midline; a *depressor* lowers a part; while a *rotator* rotates one part upon another. Muscles function by contracting. Thus, flexing the forearm is brought about by a contraction of the *biceps* muscle, and its extension by

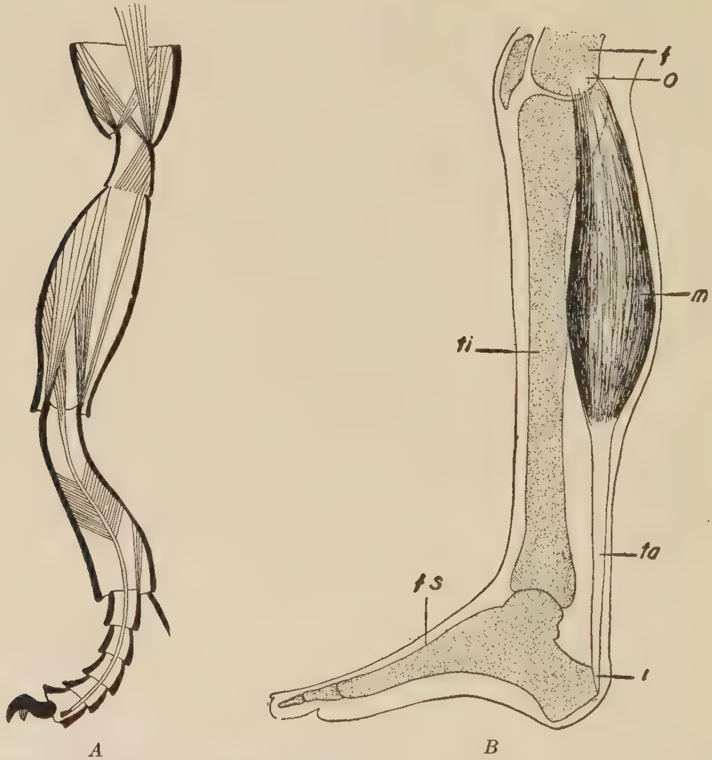


FIG. 39.—Relation of muscle to hard parts in the appendages of insect and man. A, leg of insect. B, leg of man. *f*, femur; *fs*, skeleton of foot; *i*, insertion of muscle; *m*, muscle; *o*, origin of muscle; *ta*, tendo Achilles; *ti*, tibia. (*A after Berlese; B after Hesse and Doflein. Both from Shull, LaRue and Ruthven; Animal Biology.*)

a contraction of the *triceps* muscle, accompanied by a relaxation of the biceps. Muscles about joints are arranged in antagonist groups—when one group contracts the other group relaxes proportionately.

The *cardiac muscle* of the vertebrate is arranged in the form of a spiral so that when the heart contracts the blood is wrung

out of the heart like water out of a cloth, except that in the heart the fluid is squeezed out of the heart chambers instead of interstices in its walls. The relation of the heart to the blood vessels is considered in connection with the organs of circulation.

Smooth muscle is much slower in its action than either skeletal or cardiac muscle. In the skin it causes movements of the skin and the hair; in the walls of blood vessels it controls the volume of blood passing through by regulating the caliber of the vessel. Thus, blushing is caused by *vasodilation* and pallor by

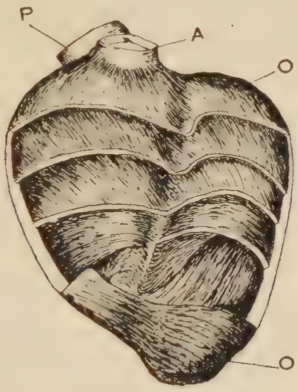


FIG. 40.—View of a partial dissection of the fibers of the ventral wall of the ventricle of the sheep's heart designed to show the different degrees of obliquity of the fibers. The general direction of the superficial fibers is oblique. At the apex of the heart (below) they produce a whorl as they pass internally to become continuous with the fibers of the inner layer, thus forming a double spiral. A, aorta; P, pulmonary artery; O, outer surface of the superficial layer of fibers. The slightly oblique groove marks the division between the ventricles. (*Adapted from Allen Thompson, Quain's Anatomy, Longmans, Green & Co. By permission.*)

vasoconstriction of the blood vessels of the face. The entire digestive tract of vertebrates is provided with smooth muscle, arranged for the most part in two layers: an inner circular and an outer longitudinal layer. Movement of the contents of the alimentary canal is brought about by slow waves of contraction of these muscles.

References

The following list applies also to Chaps. V to X inclusive.

KINGSLEY, J. S.: Hertwig's "Textbook of Zoology," H. Holt & Company, 1912.

Kingsley, J. S.: "Vertebrate Zoology," H. Holt & Company, 1917.
Parker, J. T. and Haswell, W. A.: "Textbook of Zoology," The Macmillan Company, 1921.
Shipley, A. E. and MacBride, E. W.: "Zoology," The Macmillan Company, 1901.
Wiedersheim, R.: "Comparative Anatomy of Vertebrates," The Macmillan Company, 1907.
Wilder, H. H.: "History of the Human Body," H. Holt & Company, 1923.

CHAPTER V

ORGANS OF DIGESTION

Metabolism results in a continuous evolution of energy and loss of material in the living body which is made good by taking in oxygen and food, but before the energy-containing constituents can be utilized, the food must be *digested* and the products *absorbed*. Digestion converts solids into liquids, but the process involves something more than liquefaction, because liquid food also requires digestion. The organs of digestion include, besides the alimentary canal in which digestion and absorption take place, a number of glands, like the *salivary glands*, *liver*, and *pancreas*, whose *secretions* play an important part in the digestive process. In the following paragraphs some types of alimentary systems are described, the examples selected being those of animals ordinarily studied in the laboratory.

Gastrovascular Cavity.—A simple kind of alimentary tract is that of the common *Hydra*, a tube-shaped animal found in fresh water, its length varying from 2 to 20 millimeters. The closed end of the tube is attached by a basal disc to the substratum, usually a plant; the opposite, free end is open and serves as a mouth. It is surrounded by from six to ten small tubes, called *tentacles*, closed at their outer ends. The body wall consists of two well-defined cellular layers, an outer *ectoderm* and an inner *endoderm*, with some indication of a third layer between them. The third layer, known as the *mesoglœa*, is non-cellular and jelly-like in appearance. Since only two embryonic germ layers, the ectoderm and endoderm, are developed, the animal is said to be *diploblastic*. The cavity of the tube, the *gastrovascular* cavity, is the digestive cavity (Fig. 41).

Food captured by the tentacles passes through the mouth into the gastrovascular cavity, where it is acted upon by a secretion of the cells lining the cavity. Some of the food is digested in this way; and some of it apparently is engulfed by the endodermal cells to undergo *intracellular* digestion, something after the manner of amœba. The products of *extracellular* digestion

are absorbed by the endoderm and any undigested remains are cast out through the mouth. From the endoderm, absorbed food is distributed to the ectoderm by cell-to-cell transfer. The simple digestive tube of Hydra may be regarded as an early step in the evolution of the digestive tract of higher forms.

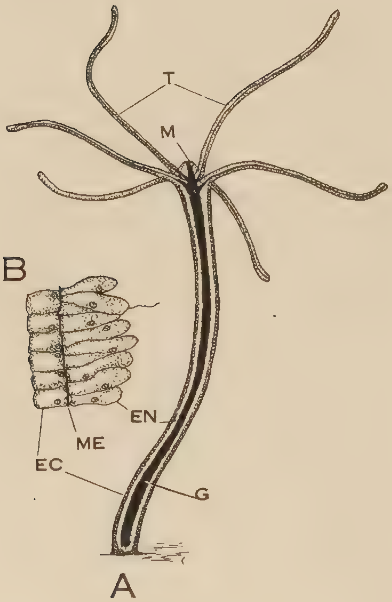


FIG. 41.

FIG. 42.

FIG. 41.—A, *Hydra*, expanded, diagrammatic; B, longitudinal section of body wall. EC, ectoderm; EN, endoderm; G, gastrovascular cavity, shown in black; ME, mesoglœa; M, mouth; T, tentacles.

FIG. 42.—Digestive and nervous system of a flatworm, *Planaria*; the digestive system shown in solid black. G, ganglionic mass; I, intestine; P, pharynx. (*Based on von Graff.*)

The flatworm, *Planaria*, may be utilized to illustrate a modification of the same type of canal. This animal is also a fresh-water form, of common occurrence in ponds. Its body measures about 12 millimeters in length, and in shape is flattened and elongated, being blunt at its anterior end and pointed posteriorly. A ciliated layer of ectoderm covers the outside, and an inner

layer of endoderm lines an alimentary tract. Between the two is muscle tissue and other organs derived from a third germ layer, the *mesoderm.* Planaria is, therefore, *triploblastic.* The opening into the alimentary canal is on the ventral surface of the body near the middle through which a muscular tube, the *pharynx,* can be thrust like a proboscis. Inside the body the pharynx connects with an *intestine* consisting of three main trunks, one forward and two backward, from each of which numerous smaller branches, ending blindly, penetrate among the tissues. Digestion, both intercellular and extracellular, takes place in the intestine, which also serves to distribute the products to the tissues by means of its collateral branches.

Complete Alimentary Canal.—The digestive organs of an *insect,* like the *grasshopper,* display a considerable advance in

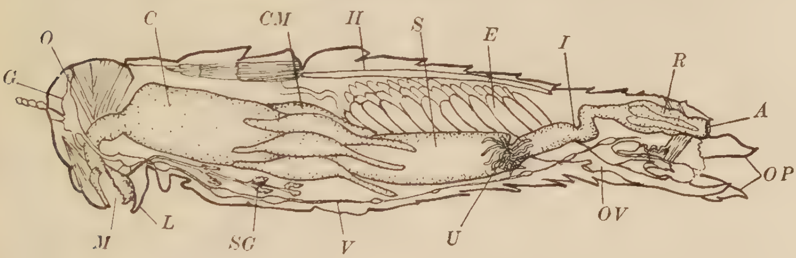


Fig. 43.—Internal anatomy of a grasshopper. *A,* anus; *C,* crop; *CM,* cæcum; *E,* eggs; *G,* supracœsophageal ganglion; *H,* heart; *I,* intestine; *L,* labium; *M,* mouth; *O,* œsophagus; *OP,* ovipositor; *OV,* oviduct; *R,* rectum; *S,* stomach; *SG,* salivary gland; *U,* Malpighian tubules; *V,* ventral nerve cord. (*After Packard, Textbook of Entomology.*)

complexity over the preceding forms, and have many features in common with the vertebrate type of system. The alimentary canal of the grasshopper is a tube open at both ends, beginning with a mouth and terminating in an anus, and is what is known as a complete alimentary canal. The tube lies in a cavity of the body, the *hæmocœl,* which is filled with blood. The mouth is provided with organs of mastication: a *labrum,* or upper lip; a *labium,* or lower lip; and between them a pair of *mandibles* and a pair of *maxillae.* The latter are the principal chewing organs, and they operate by a side-to-side movement, instead of up and down as with the jaws of man. The mouth leads to a narrow tube, the *gullet,* extending upward to about the center of the head, where it turns posteriorly to dilate into the *crop.* The latter is lined with a cuticular membrane armed with tooth-

like projections for completing the process of mastication begun in the mouth. Alongside the crop are branched *salivary glands* whose ducts run forward to empty into the mouth. Next comes the *stomach* surrounded by a set of six to eight double cone-shaped pouches, known as *cœca,* which secrete a digestive fluid. The posterior limit of the stomach is marked by large number of *Malpighian tubules,* excretory in function, which enter the digestive tube at the junction of the stomach with the *intestine.* The latter passes back to terminate at the tip of the abdomen in an *anal* opening. The *rectum* is an enlargement in the intestine near the anus where fecal matter accumulates until excreted.

Digestion and *absorption* in the grasshopper take place in the stomach and intestine, whence the products of digestion pass into the body fluid filling the hemocœl. The body fluid and the blood in insects is the same, and is pumped by the heart to all parts of the body, supplying the tissues in this way with nutrition and at the same time ridding them of the waste products of metabolism. Undigested food and excretory products are expelled through the anus.

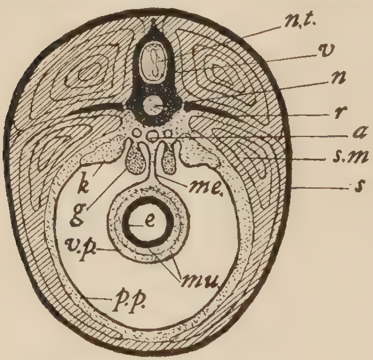


Fig. 44.—Diagram of a cross section of vertebrate body. *a*, aorta; *e*, mucosa, the endodermal lining of the alimentary tract; *g*, gonad; *k*, kidney; *me*, mesentery supporting the alimentary canal; *mu*, muscularis coats of alimentary canal; *n*, notochord; *n.t.*, neural tube; *p.p.*, parietal peritoneum; *r*, pleural rib; *s*, skin; *s.m.*, body musculature; *v*, vertebra; *v.p.*, visceral peritoneum.

Vertebrates.—The vertebrate alimentary canal is also a complete alimentary canal, which, however, differs in many important details from that of the grasshopper. It is a tube with an opening at either end and suspended throughout the greater portion of its length by a *mesentery* attached to the dorsal wall of the body cavity or *cœlom.* The cœlomic cavity is a distinct space lined with a sheet of mesothelium, the *peritoneum,* which is reflected at the middorsal line so as to surround the alimentary canal and other organs suspended in it. The mesentery is a thin double-walled membrane formed by the meeting of the mesothelium from either side in midline from which it is suspended with the alimentary canal enclosed in its walls at its free

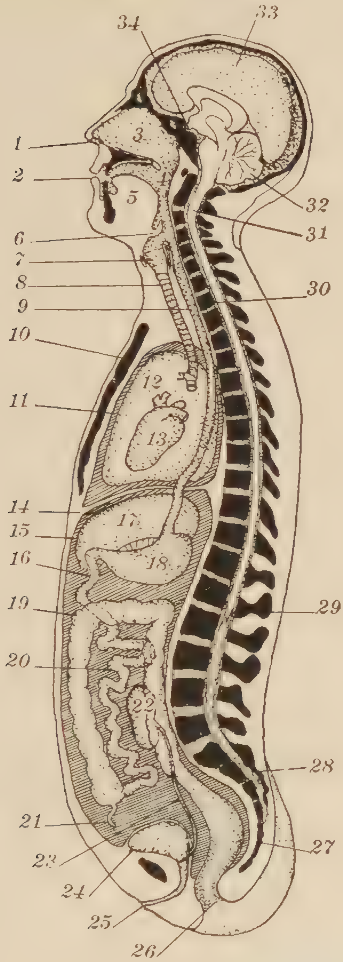


Fig. 45.—Median section of the human body showing the alimentary canal and other viscera diagrammatically disposed; bone is shown in solid black. 1, external nares; 2, mouth; 3, nasal passage; 4, pharynx; 5, tongue; 6, epiglottis; 7, larynx; 8, trachea; 9, œsophagus; 10, sternum; 11, pleural cavity; 12, lung; 13, heart; 14, diaphragm; 15, abdominal cavity; 16, duodenum; 17, liver; 18, stomach; 19, large intestine; 20, ileo-jejunum; 21, vermiform appendix; 22, kidney; 23, ureter; 24, bladder; 25, urethra; 26, anus; 27, coccyx; 28, sacrum; 29, neural spine of first lumbar vertebra; 30, centrum of first thoracic vertebra; 31, spinal cord; 32, cerebellum; 33, cerebrum; 34, pituitary body.

edge. The mesothelium (so-called from its origin from mesoderm), which bounds the body cavity and forms the mesentery and the bounding membrane of the alimentary canal, is a continuous membrane.

The mouth opens into an *oral cavity,* which usually contains tongue, teeth, and openings of oral glands. Posteriorly, the oral cavity continues into the *pharynx,* a region that is important in connection with respiration. The walls of the pharynx develop gill clefts, gills, lungs, or derivatives of these; and if nasal passages are present their internal openings are in the pharynx. The remainder of the alimentary canal is made up of the *œsophagus, stomach,* and *intestine,* the latter terminating at the *anus.* In vertebrates below mammals the intestine opens into a *cloaca,* a wide chamber, open to the outside, which also receives the openings of the excretory and genital ducts. In mammals generally, the alimentary canal and urogenital systems have separate openings, an exception being the *Prototheria,* which have a cloaca.

Teeth.—These organs for masticating food are present in practically all vertebrates, notable exceptions being birds and some reptiles (turtles). There is a close adaptation between the form and development of the teeth and the nature of the food. Thus, in mammals the teeth are for the most part *heterodont* in character, which means that they are differentiated into several sorts, each having distinct functions. The *incisors* in front are mainly prehensile, the *canines* are adapted for grasping or tearing, the *premolars* for shearing or, like the *molars,* for grinding. Many degrees of variation are found.

Among *Carnivora* the cheek teeth are high-crowned trenchant organs, and the jaws have practically no side play, a condition which reaches its highest development in cats, which have no true grinding teeth. Dogs, living on a less restricted carnivorous diet, have some shearing teeth and also grinders. Omnivorous bears lack shearing teeth, but do have well-developed grinders. Carrion-eating forms have blunter teeth, while fish eaters, like seals, have teeth that are all pointed and prehensile.

Herbivora have teeth of a quite different character. The incisors may be present in both jaws and adapted for seizing or cutting, as in the horse; but in *ruminants,* like the ox, they are absent in the upper jaw, which is provided with a tough pad against which the incisors of the lower jaw bite. Canine teeth

FIG. 46.—Upper teeth of the dog. C, canine; I, incisor; P, premolar; M, molar. The carnasial or flesh-cutting tooth is the fourth premolar.

FIG. 47.—Side-view of the upper teeth of the sea-lion showing the peg-like character of all them.

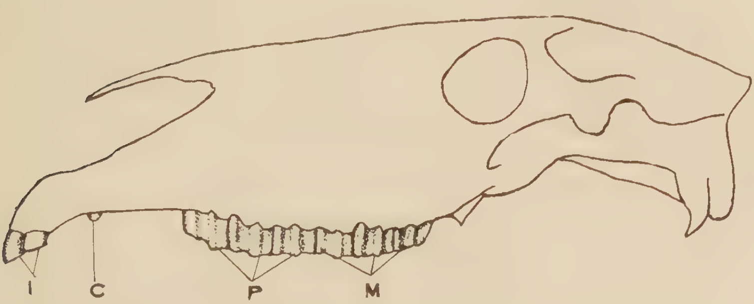


FIG. 48.—Side view of the upper teeth of the horse, *i*, incisors; *c*, canine; *p*, premolars; *m*, molars.

are not well developed in Herbivora, unless they are used for defense or for digging (*swine*). The remaining teeth are adapted for grinding, and the jaw is hinged so as to permit considerable

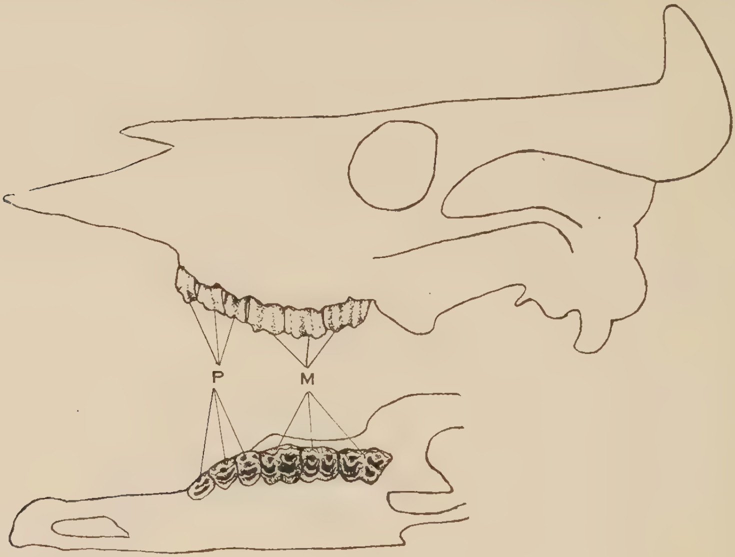


FIG. 49.—Side and ventral view of the upper teeth of the ox. *p*, premolars; *m*, molars.

lateral motion. The side play of the lower jaw is familiar to anyone who has watched a cow chewing its cud.

Tongue.—The tongue of fishes is a simple and practically immovable structure in the floor of the mouth. Above the fishes there is considerable variety in the shape and use of the tongue. In the frog it is attached at the margin of the lower jaw and its free end when at rest is folded back on the floor of the mouth. Among mammals, except for whales, the tongue is very movable, and is used in most cases in grasping food and chewing it.

FIG. 50.—Showing tongue of frog fully extended.

Oral Glands.—These glands do not lie in the oral cavity, but they produce a secretion that is poured into the cavity by means of ducts leading from the glands. This secretion moistens the food in mastication, lubricates it for swallowing, and in some

cases has a digestive property. In mammals, three kinds of oral glands are recognized: the *parotid*, *sublingual*, and *submaxillary*. The parotid gland lies on the side of the head near the ear, and its duct enters the mouth by piercing the cheek near the molars of the upper jaw. The sublingual gland lies between the tongue and the margin of the lower jaw, and opens by several ducts into the floor of the mouth. The submaxillary gland lies inside of the lower jaw, and its duct opens near the lower incisor teeth. All of these glands are paired.

The secretions of the different glands vary. In man the submaxillary and the sublingual produce most of the *mucin*, the substance which gives saliva its ropy, mucilaginous character; while the secretion of the parotid is more watery and contains *ptyalin* in larger amounts than the other two. Ptyalin is a digestive ferment which acts upon starchy food.

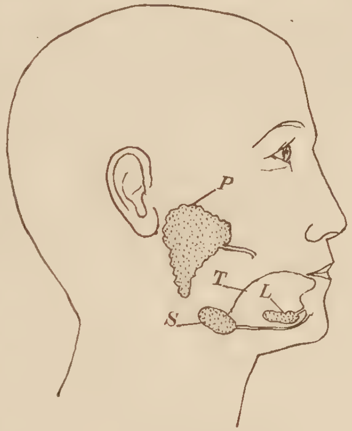


FIG. 51.—Diagram showing location of the salivary glands in man. L, sublingual; M, sub-maxillary; P, parotid; T, tongue.

Pharynx.—The pharynx, so far as alimentation is concerned, is merely a connection between the oral cavity and the œsophagus. It is, however, very important in respiration, which is taken up in the next chapter.

Œsophagus.—The œsophagus is, for the most part, a tube supplied with muscular walls for conducting food from the oral cavity and pharynx to the stomach. Frequently in birds it has a marked dilation, the *ingluvies*, or crop, which is primarily a reservoir for food, although sometimes its walls are glandular. In the pigeon it secretes a milky fluid that is regurgitated and fed to the young.

Stomach.—The stomach in fishes and lower vertebrates is generally but little more than a dilation in the digestive tract, serving as a food receptacle in which a certain amount of digestion takes place. The anterior portion of the stomach is called the *cardia* or cardiac end, and the posterior part the *pylorus*, the opening of which into the intestine is guarded by a thick, circular muscle, the *pyloric sphincter*. The walls of the stomach consist

of four layers, which, beginning at the outside, are: (1) the *serous membrane*, or *visceral peritoneum*, a continuation of the mesentery suspending the stomach; (2) the *muscularis*, consisting of an inner circular and an outer longitudinal layer of smooth muscle; (3) the *submucosa*, made up of connective tissue (areolar), blood vessels, lymphatic vessels, and nervous tissue (*plexus of Meissner*); and (4) the *mucosa*, the glandular epithelium lining

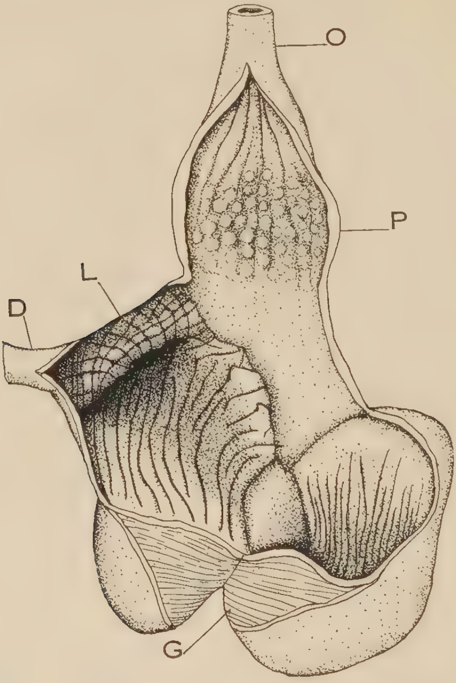


FIG. 52.—Stomach region of the domestic fowl, cut open. D, duodenum; G, gizzard, showing thicknesses of muscular wall; L, cornified lining of gizzard; deeply creased; O, œsophagus; P, proventriculus, showing rounded elevations of its soft glandular lining.

the stomach. Between the two muscular coats is another important nervous network, the *plexus of Auerbach*.

In birds there are two distinct regions in the stomach, an anterior glandular part, the *proventriculus*, and a highly muscular posterior part, the *gizzard*. The glands of the proventriculus produce a secretion that mixes with the food before it passes to the gizzard to be ground up. As teeth are absent in birds, the gizzard is the organ of mastication, for which function it is

especially adapted by having thick muscular walls lined with a tough, horny membrane. The process of trituration is further facilitated in grain-eating birds by small pebbles swallowed with the food. The degree to which the gizzard is developed is correlated with the nature of the food. In carnivorous birds the muscles of the gizzard are poorly developed.

Among mammals, the stomach of the *ruminant* shows special features that are correlated with its cud-chewing habit. Animals of this sort have a stomach consisting of four parts as follows: (1) the *rumen* or *paunch*, (2) the *reticulum* or *honeycomb*, (3) the *psalterium omasum*, and (4) the *abomasum*. The first two divi-

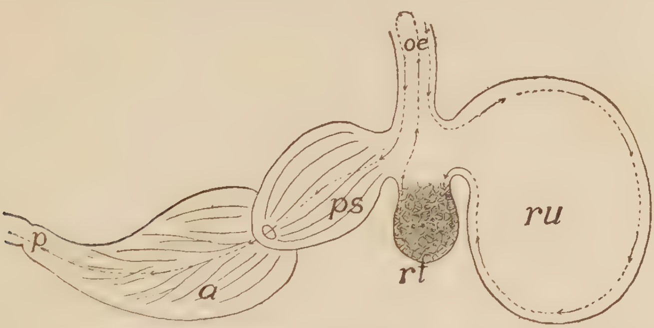


FIG. 53.—Diagram of ruminant stomach, the dotted line showing the course of the food. *a*, abomasum; *oe*, œsophagus; *p*, pylorus; *ps*, psalterium (omasum, manyplies); *rt*, reticulum (honeycomb); *ru*, rumen (paunch). (*From Kingsley, Comparative Anatomy of Vertebrates, P. Blakiston's Son & Co. By permission.*)

sions seem to be a modification of the lower end of the œsophagus, serving primarily as food reservoirs. In feeding, vegetation is cropped by the incisors of the lower jaw and swallowed unmasticated into the rumen and reticulum. When the animal stops grazing, it seeks a quiet spot and begins to chew its cud. In this process food is regurgitated from the reticulum to the mouth and then thoroughly masticated by the molar teeth. When the food is swallowed the second time, it passes into the psalterium and later into the abomasum, where it undergoes gastric digestion.

The stomach of Carnivora is relatively simple and, as a rule, rather closely resembles the human stomach. The latter is a pouch-shaped organ in which, in addition to the cardia and pylorus, a third region is recognized, known as the *fundus*. The three regions are merely parts of a single chamber, the

principal basis of distinction being the difference in the character of the glands of the mucosa. The actual shape of the stomach varies considerably in different individuals and in the same individual under different conditions. When empty, its walls are collapsed, and after a meal its outlines are continually changed by waves of constriction, beginning at about the middle and passing to the pylorus, which serve to churn the contents and eventually to expel it into the intestine.

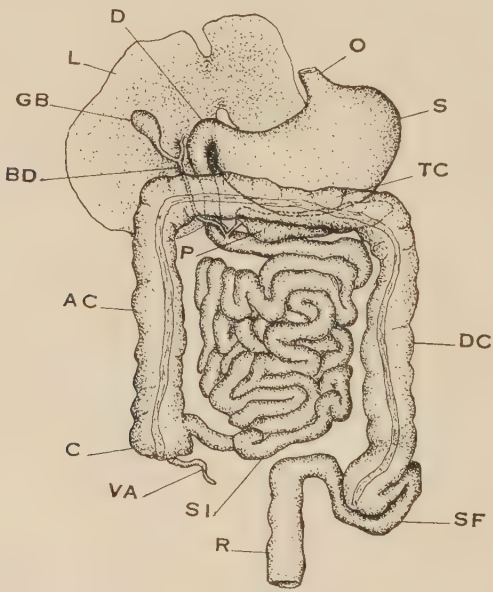


FIG. 54.—Human alimentary tract, diagrammatic. AC, ascending colon; BD, bile-duct, extending from the liver to the duodenum; C, cæcum; D, beginning of duodenum; DC, descending colon; GB, gall-bladder; L, liver, turned up so as to show its under surface; O, end of œsophagus; P, pancreas, whose duct connects with the duodenum near the end of the bile-duct; R, rectum; S, stomach; SF, sigmoid flexure of descending colon; SI, small intestine; TC, transverse colon; VA, vermiform appendix.

Intestine.—The intestine is the tube leading from the stomach and terminating at the anus. It consists of two general regions, the *small* and the *large intestine.* Its walls are made up of four layers similar in general arrangement to the walls of the stomach, but differing in histological details, especially as regards the mucosa.

In the small intestine of *man* two regions are recognized; (1) the *duodenum,* extending from the stomach to the point where

the bile duct from the liver enters the intestine; and (2) the *jejuno-ileum*, forming the remainder. In all the higher vertebrates the small intestine joins the large at right angles, forming a blind pouch, the *cæcum*, at the proximal end of the large intestine. The cæcum is greatly reduced in carnivorous animals,

FIG. 55.—Spiral valve of *Raia*. The arrow indicates the direction in which the food passes. (*Modified after Mayer.*)

but is of considerable length in plant-eaters. The *vermiform appendix* is the reduced end of the cæcum. The *colon* and the *rectum* form the remainder of the large intestine. At the point where the small intestine joins the large is a ring-like thickening in the circular muscle, known as the *ileocæcal valve*, which controls the passage of *chyme* (food in the process of digestion) into the colon.

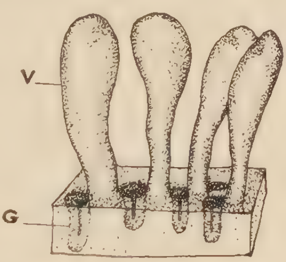


FIG. 56. Diagram of surface of mucosa of small intestine of man. G, intestinal gland opening on the surface between the bases of the villi; V, villus.

The small intestine shows interesting adaptations for increasing its effectiveness as an organ of digestion and absorption. Thus, an increase in digestive and absorptive surface may be brought about (1) by an elongation of the tube to a length much greater than that of the body, and (2) by the mucosa developing folds, circular and longitudinal in the *spiral valve* of the dogfish, and finger-like in the *villi* of mammals. There is also a close adaptation between the nature of the food and the amount of absorptive and digestive surface. Plant-eating animals require a larger amount of food than carnivorous animals, and therefore a relatively greater digestive and absorptive surface, because vegetable matter contains less nutriment than an equal volume of animal matter. Thus, one can understand why the frog tad-

pole living on vegetable matter has an alimentary canal relatively much longer than that of the adult frog, since the latter is carnivorous in its diet. In general, the length of the alimentary canal of the Herbivora is from twenty to twenty-eight times the length of the body, while in Carnivora it is only from five to six times the body length. This, of course, also accounts for the fact of the greater length of the cæcal appendage in Herbivora.

Liver and Pancreas.—The liver is a large gland whose external secretion, *bile*, is conveyed to the small intestine through the *bile duct.* Bile contains no digestive agent, still it is essential for digestion, especially the digestion of fats. The pancreas is also a gland, and its secretion, the *pancreatic juice,* contains substances that have a digestive action upon food. The *pancreatic duct,* which carries the secretion from the gland, enters the small intestine at or near the opening of the bile duct.

CHAPTER VI

ORGANS OF RESPIRATION

Respiration is an important phase of metabolism, since every living thing consumes oxygen and gives off carbon dioxide. When respiration ceases, death ensues. *Organs of respiration,* on the other hand, merely facilitate the process by making it possible for every cell in the body to obtain its proper supply of oxygen and get rid of its carbon dioxide. As a result, organs of respiration vary considerably in form and arrangement in different animals. *Protozoa* and other animals of small size carry on respiration at the surface of the body, but in the majority of *Metazoa* the surface area is entirely inadequate to meet the needs of the interior of the body, so that a special mechanism is required.

Gills.—Among aquatic invertebrates, a gill of some sort is the organ of respiration which enables respiratory changes to occur

FIG. 57.—*Amblystoma punctatum,* with external gills which disappear at metamorphosis.

at the surface of the body between the blood and the water; the blood serving to carry oxygen to the tissues and remove the carbon dioxide from them. Gills in these cases are filamentous or plate-like outgrowths of the integument, located at the surface of the body where they are continually bathed by water. They are richly supplied with blood vessels, and as the blood circulates through them it absorbs oxygen, dissolved in the water, and gives off carbon dioxide. A similar kind of gill is found in the *larval* (embryonic) stages of many amphibians and is likewise located on the outside of the body. In some amphibians, like the *mud puppy* (*Necturus*), the gills persist

throughout life, but in the frog and terrestrial salamanders they are replaced by lungs at metamorphosis.

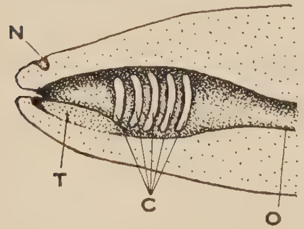


FIG. 58.—Diagram of one side of the mouth and pharynx of a fish, split lengthwise. C, gill-clefts, separated by gill arches; N, nasal pit; O, œsophagus; T, tongue.

FIG. 59.—*Salmo iridens*, the rainbow trout, with the gill cover bent back to show the gills. (*After Jordan and Kellogg, Animal Life and Evolution.*)

In *fishes*, on the other hand, the gills are a development of the endoderm of the pharynx, which is also pierced with *gill clefts* forming passageways to the outside. *Septa* between the clefts bear the gills and are, in turn, supported by skeleton structures known as *gill arches*. The gills are thin-walled plates whose rich blood supply gives the red color to the gills. Water, entering at the mouth and passing out through the clefts, flows over the gills and aerates the blood.

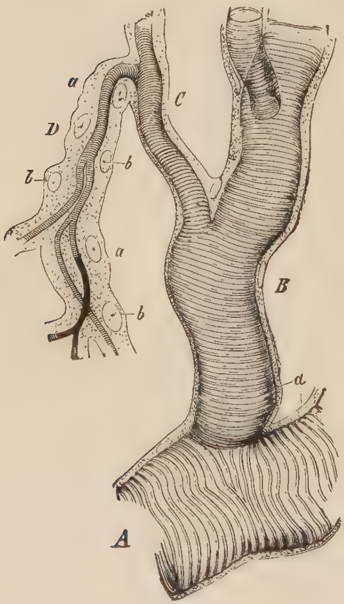


FIG. 60.—*A*, portion of trachea of caterpillar with its branches, *B*, *C*, *D*. *a*, peritracheal membrane; *b*, nucleus. (*From Packard, "Text book of Entomology," The Macmillan Company. By permission.*)

Tracheal System.—Insects have a highly efficient organ of respiration consisting of a series of tubes, *tracheae*, which, beginning with openings called *spiracles* arranged along the sides of the body, divide into smaller and smaller tubes within, finally terminating in capillaries in the tissues. Under the microscope the tracheal tubes have a ringed appearance due to the presence of transverse folds in the walls, arranged in a close spiral, which serve to keep the tubes distended. Air enters and

leaves through the spiracles, being pumped back and forth through the tubes by muscular contractions of the body. Oxygen is given off directly to the tissues from the tracheal capillaries, the blood playing no part in the process. At the same time carbon dioxide passes from the tissues to the tracheae, whence it is removed.

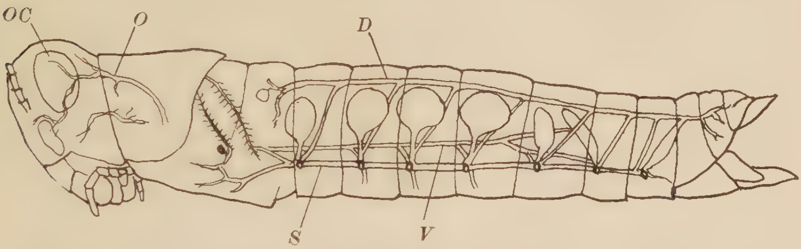


FIG. 61.—The distribution of tracheae and air-sacs in a grasshopper. *V*, ventral tracheae; *S*, left stigmatal trachea with stigmata (spiracles); *D*, left dorsal trachea; *C*, left cephalic trachea; *OC*, ocular trachea. (*After Packard, Textbook of Entomology.*)

Recent work by Lee (1925) indicates that in nine species of grasshoppers, the two pairs of thoracic and the first two pairs of abdominal spiracles are solely inspiratory in function, while the last six pairs of abdominal spiracles are expiratory. According to Lee, then, there is a definite circulation of air through the tracheal system in these insects.

Lungs.—The organs of respiration of air-breathing vertebrates are the lungs. They are usually paired and lie in the body cavity. While considerable difference exists in the form and structure of the lungs in different groups, they always consist of highly vascular tissue, the blood of which is separated from the air cavities by a very thin epithelium permitting a ready exchange of gases. Functionally, they act like gills, the only difference being that oxygen is taken directly from the air instead of from the water.

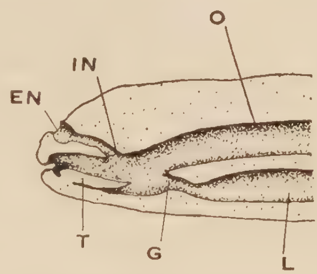


FIG. 62.—Diagram of one side of mouth and pharynx of the frog. EN, external nares; G, glottis; IN, internal nares; L, lung; O, œsophagus; T, tongue.

The Respiratory Passage.—Beginning with the *external nares* opening from the outside into *nasal passages* connecting with the pharynx by *internal nares* is the respiratory passage. In the

floor of the pharynx is the *glottis*, an elongated slit opening into the *larynx*. The latter is a box-like structure with a cartilaginous framework containing in its interior the *vocal cords* formed of a pair of folds of the larynx running parallel to the margin of the glottis. The larynx with its cords is the vocal organ. It is poorly developed in reptiles and birds. A single tube, the *trachea* (absent in *Amphibia*), passes backward from the larynx to branch right and left into two *bronchi*, one to each lung. The walls of the trachea and bronchi are provided with semicircular pieces of *cartilage* to keep the walls distended. In birds, at the point of division of the trachea into the bronchi is an enlargement called the *syrinx*, whose walls contain sound-producing membranes vibrated by the passage of air.

In the *frog* the lungs are simple sacs from the lining of which project slender partitions extending a short way toward a central air cavity. When the floor of the mouth is lowered, the air is drawn in through the external nares. The latter are then closed and the floor of the mouth raised, which results in air being forced through the glottis into the lungs, inflating them. The lungs are emptied by the opening of the external nares, which, by reducing the pressure, allows the elastic walls of the lungs to contract. The skin is also respiratory, being richly supplied with cutaneous blood vessels. In some species of terrestrial salamanders this is the sole method of respiration, lungs being entirely lacking.

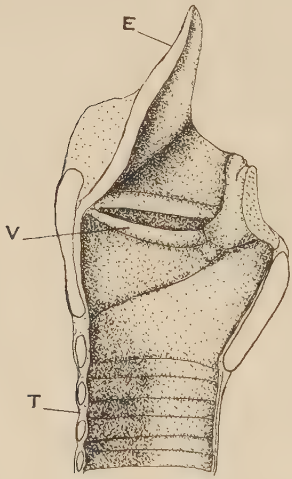


FIG. 63.

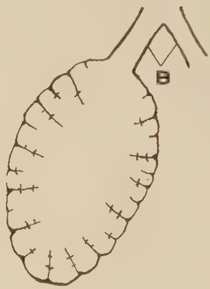


FIG. 64.

FIG. 63.—View of right half of interior of larynx of man, somewhat diagrammatic. E, epiglottis, which projects over the opening of the glottis; T, upper end of trachea whose walls are supported by cartilaginous rings; V, vocal cord. See Fig. 45 for relation to other parts.

FIG. 64.—Diagrammatic longitudinal section of frog's lung. B, bronchi.

The lungs of *birds* have extensions in the form of thin-walled *air sacs* which penetrate between the viscera and into the cavities of the bones, such as the *humerus*, *sternum*, *coracoid*, and sometimes the *femur*, *furcula* (wishbone), and *scapula*. The air sacs give buoyancy to the body but also facilitate respiration, especially during flight, by increasing the air capacity and allowing the air to pass twice over the respiratory epithelium of the lungs. The lungs are attached to the ribs and vertebral column, so that when the ribs are raised the air is drawn into the lungs; when the ribs are lowered, air is forced out. During flight the thoracic framework probably remains rigid, or practically so, in order to supply a firm attachment for the pectoral muscles, under which conditions respiration is effected by a pump-like action of the air sacs as they are subjected to varying pressure from the movement of parts about them. The air sacs have probably a greater significance in respiration than in giving buoyancy, although the latter is an important factor in flying as well.

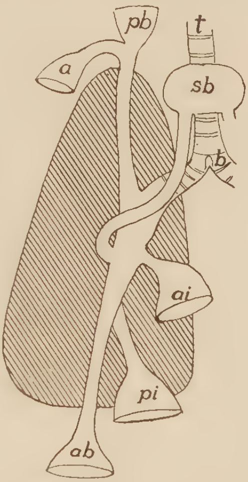


Fig. 65.—Diagram of the relations of the chief air-sacs in a bird, lung tissues shaded. *a*, axillary sac; *ab*, abdominal sac; *ai*, anterior intermediate sac; *b*, bronchus; *pb*, prebronchial sac; *pi*, posterior intermediate sac; *sb*, subbronchial sac; *t*, trachea. (*From Kingsley. Comparative Anatomy of Vertebrates, P. Blakiston's Son and Company. By permission.*)

The body cavity of mammals is divided by a muscular partition, the *diaphragm*, into a thoracic cavity containing the heart and lungs, and an abdominal cavity containing the digestive and other organs. Each lung lies in a *pleural cavity* bounded by the *parietal pleura* which is reflected about the lung, the relation being similar to that of the peritoneum to the alimentary canal. Between these two pleural sacs lies the *pericardium* containing the heart. The lungs are not attached to the ribs. The mammalian lung is a spongy structure in which a large central cavity is absent. Each *bronchus* on entering the lung breaks up into smaller and smaller branches that finally terminate in thin-walled *air chambers*. The result of this arrangement is an enormous amount of respiratory surface in proportion to the size of the organ as a whole.

Respiratory Movements.—Air is drawn into the lungs and expelled by the action of muscles. The ribs are articulated to the vertebral column at an angle, so that when the ribs are raised they are rotated outward and the size of the pleural cavities

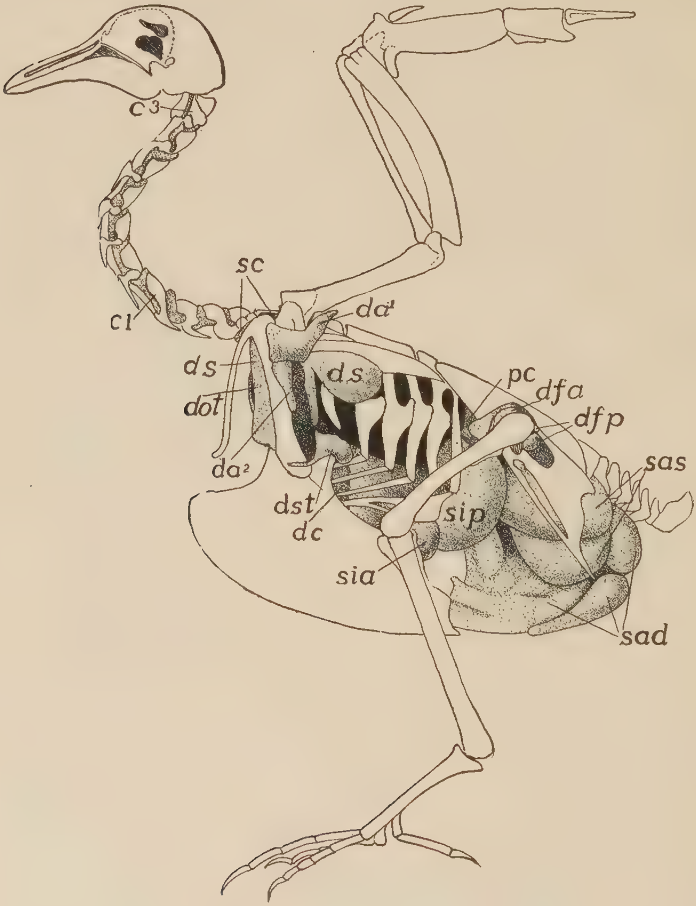


FIG. 66.—Air-sacs of pigeon. c^1, c^3, intertransverse canal; da^1, da^2, axillary diverticulum and its ventral outgrowth; *dc*, diverticulum costale; *dfa*, *dfp*, divert. femorale, anterior et posterior; *dot*, divert. œsophageo-tracheale; *ds*, divert. subscalulare; *dst*, divert. sternale; *pc*, preacetabular canal; *sad*, *sas*, saccus abdominale, dexter et sinister; *sc*, saccus cervicalis; *sia*, *sip*, saccus intermedius, anterior et posterior. (*From Kingsley, Comparative Anatomy of Vertebrates, P. Blakiston's Son & Co., after Bruno Muller. By permission.*)

(and the lungs) is increased. Contraction of the dome-shaped diaphragm lowers its center, and also enlarges the pleural cavities. Enlargement of these cavities reduces the air pressure

in the lungs, as a result of which air rushes in from the outside until equilibrium is restored. Expiration is accomplished by lowering the ribs and raising the diaphragm, the elasticity of the lungs aiding in expelling the air. Between the ribs are an inner and an outer layer of intercostal muscles. The fibers of the *external intercostal muscles* run downward and forward from the lower border of one rib to the upper edge of the following rib. The fibers of the *internal intercostal muscles* run at right angles to those of the external. These muscles are involved in changing the size of the chest by raising and lowering the ribs. It is generally agreed that the contractions of the external intercostal muscles raise the ribs. Presumably, the contractions of the internal intercostal muscles lower the ribs, but there is not complete agreement on this point. Other muscles, notably those in the anterior abdominal wall, are brought into play in forced expiratory movements accompanying unusual physical exertion.

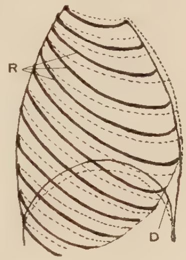


Fig. 67.—Diagram to show changes in position the ribs, R, and the diaphragm, D. The dotted lines indicate the position of the ribs and diaphragm at the end of inspiration.

Birds and mammals are *homothermous* or warm-blooded animals, which means that body temperature is relatively high and also constant. In order to maintain these conditions of body temperature, a large amount of oxygen is required, part of which comes from the food and part in a gaseous form from the air. The high degree of development of the respiratory organs in these forms is correlated with the oxygen requirements. It should be pointed out, however, that the tracheal system is also a highly efficient mechanism for facilitating rapid oxidation, since the direct delivery of oxygen to the tissues and the removal of carbon dioxide from them by the tracheal tubes contributes in no small degree to making possible the remarkable degree of muscular activity exhibited by many insects.

CHAPTER VII

ORGANS OF CIRCULATION

The circulatory system serves to distribute nutrition and oxygen to the tissues, and to collect waste products of metabolism from them. It consists of circulating fluids, *blood* and *lymph*, and a set of tubes, blood and lymphatic vessels, through which the fluids circulate. The fluid is propelled by the pulsating walls of the vessels, or by the contractions of a *heart* which is merely a portion of a vessel enlarged and specially modified for the purpose.

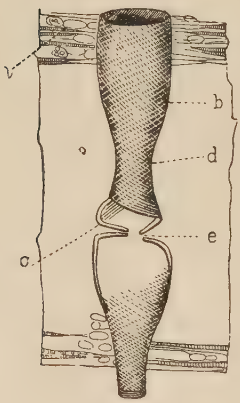


Fig. 68.—Part of heart of a beetle, *Dytiscus marginalis*, showing spiral arrangement of fibers recalling similar arrangement in the mammalian heart. *c*, closed valve; *e*, open valve; *a*, muscular and connective tissue sheet lying ventral to the heart; *b*, arrangement of fibers. (*From Packard, Textbook of Entomology, copyright, The Macmillan Co., after Grober. By permission.*)

Open or Lacunar Type.—In insects the body fluid and the blood are one and the same, and blood vessels, except in the region of the heart, are lacking. The *heart* of the grasshopper is a delicate muscular tube lying directly beneath the integument in the midline of the dorsal side of the body. It is closed at its posterior end, open at its anterior end, and along its sides is provided with a series of apertures, *ostia*, which are opened and closed by valves. Anteriorly, the heart continues forward a short distance as blood vessels.

When the heart contracts, the ostia are closed, so that the wave of constriction beginning at the posterior end and passing forward forces the blood out the anterior end. As the heart relaxes, blood enters through the ostia from the *pericardium*, an incomplete sac surrounding the heart. The blood is confined to vessels only as long as it is in the heart and its anterior continuation, throughout the remainder of its course it filters through tissue spaces until it finds its way back to the pericardium. This

kind of circulatory system is an example of what is called a *lacunar* or *open* blood vascular system. Its function in the grasshopper is to carry nutrition to the tissues and to remove waste products. In other invertebrates where, as in the crayfish, the organ of respiration is the gill, the blood is involved in respiratory changes, whereas in insects, it will be remembered, oxygen is carried to the tissues directly by the tracheal system. Further, in the crayfish the blood travels in vessels to and from the gills, although *blood sinuses* do occur in other parts of the circulation. A correlation between the circulatory and the respiratory system is a fact that may be noted generally. Thus, if the organ of respiration is *diffusely* distributed over the body, as in insects, the circulatory system is poorly developed, whereas the possession of a definitely restricted or *localized* organ of respiration (gill or lung) is always accompanied by a well-developed circulatory system.

Closed Type.—As would be expected, the blood circulatory system of vertebrates is highly developed and belongs to the *closed type*, which means that the blood is confined to vessels throughout its course. The *heart* is a muscular organ that provides the power for moving the blood. *Arteries* are vessels carrying the blood from the heart, while *veins* carry blood toward the heart. *Capillaries* are thin-walled vessels that connect arteries and veins, peripherally. It is possible in vertebrates, therefore, for the blood to make a complete circuit without leaving the bounds of the vessels.

Dogfish.—Take the circulatory system of the *dogfish*, a common marine fish, as an illustration of the type of system found in fishes. The heart, surrounded by the pericardium, lies in the anteroventral part of the body cavity directly behind the gill region. It consists of two chambers, a thick-walled *ventricle* and a thin-walled *atrium* or *auricle.* The ventricle continues forward as the *truncus arteriosus* whose inner wall carries three rows of pocket-like *valves.* Its continuation is the *ventral aorta*, which in the region of the gills gives off *afferent* arteries to them. In the gills the arteries break up into capillaries, in passing through which the blood absorbs oxygen from the water and gives off carbon dioxide. The pure or oxygenated *arterial* blood leaves the gills dorsally by the *efferent* arteries which come together from either side to form a single, median vessel, the *dorsal aorta.* This passes backward, giving off branches to various

organs and parts of the body in which they break up into capillaries.

The head region is supplied by right and left *carotid* arteries, given off from the first pair of efferent arteries. Blood is returned from the capillaries of the head by right and left *anterior cardinal* veins, and from the trunk by *posterior cardinal* veins. The anterior and the posterior cardinal veins on each side unite at the posterior level of the heart, dorsal to it, to form a short transverse vessel, the *common cardinal* vein or *duct of Cuvier*. Each of the latter in turn passes downward and medially to enter the *sinus venosus*, a thin-walled transverse sac opening into the atrium. Each common cardinal receives from the floor of the mouth an *inferior jugular* vein, and from the pectoral fin a

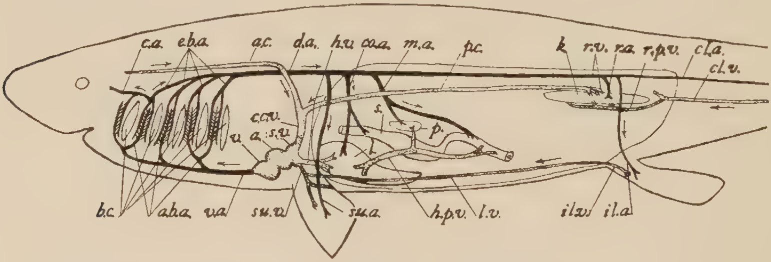


FIG. 69.—The circulatory system of the dogfish. *a*, atrium or auricle; *a.b.a.*, afferent branchial arteries; *a.c.*, anterior cardinal vein; *b.c.*, branchial clefts; *c.a.*, carotid artery; *c.c.v.*, common cardinal vein; *cl.a.*, caudal vein; *co.a.*, cœliac artery; *d.a.*, dorsal aorta; *e.b.a.*, efferent branchial arteries; *h.p.v.*, hepatic portal vein; *h.v.*, hepatic vein; *il.a.*, iliac artery; *il.v.*, iliac vein; *k*, kidney; *l*, liver; *l.v.*, lateral vein; *m.a.*, mesenteric artery; *p*, pancreas; *p.c.*, postcardinal vein; *r.a.*, renal artery; *r.p.v.*, renal portal vein; *r.v.*, renal veins; *s*, stomach; *su.a.*, subclavian artery; *su.v.*, subclavian vein; *s.v.*, sinus venosus; *v*, ventricle; *v.a.*, ventral aorta. (*Modified from Parker and Haswell.*)

subclavian vein, and from the side of the body a *lateral* vein. In some species the two latter veins empty into the anterior end of the posterior cardinal of the same side. In addition to the right and left common cardinals, the sinus venosus receives two *hepatic* veins from the liver. The *hepatic portal* vein is formed by the confluence of veins draining the stomach, intestine, pancreas, and spleen; and runs forward to the liver where it breaks up into capillaries. The two *renal portal* veins are formed by the single *caudal* vein from the tail dividing into two at the hinder end of the body cavity. Each renal portal vein then proceeds to a kidney, in which it breaks up into capillaries. The blood is removed from the kidneys by *renal* veins, which

in turn empty into the posterior cardinals. It is to be noted that both the liver and kidneys, like other organs, receive an arterial blood supply from the aorta. Both the hepatic and the renal portal veins begin and end in capillaries.

The blood that is returned to the sinus venosus is *venous* blood, that is, it is blood that has lost oxygen and gained carbon dioxide in passing through the capillaries of the body. Contraction of the sinus venosus drives the blood through an opening guarded by a *valve* into the atrium, whose contraction in turn passes the blood through another opening, also guarded by a valve, into the ventricle. The valves are like doors that open only in one direction. The contraction of the thick muscular ventricle pushes the blood out through the truncus arteriosus and ventral aorta to the gills, then through the rest of the body back to the sinous venosus.

When the ventricle contracts, the ventral aorta is distended by the extra quantity of blood forced into it. The contraction of its elastic walls on the rebound tends to reduce the size of the vessel, and the blood is driven forward, in the only direction it can go, the *semilunar valves* in the truncus preventing backflow to the heart.

Frog.—The circulatory systems of the higher vertebrates are modifications of the type illustrated by the dogfish. In the *frog*, which may be taken as an example of an air-breathing vertebrate rather low in the scale, the heart is *three-chambered*, consisting of one ventricle and two atria or auricles. The right atrium has on its dorsal aspect the opening of the sinus venosus through which venous blood enters. The left atrium receives through a single opening the pure or arterial blood brought from the lungs by the right and left pulmonary veins. The atria are separated by a thin partition, but open by a common *atrio-ventricular* aperture into the ventricle. The *truncus arteriosus* or *conus* leaves the ventricle from the right side of its base, the apex of the ventricle being pointed backward. The opening into the conus is guarded by three *semilunar valves*, while the entire length of the conus itself is traversed by a flap-like *longitudinal valve*, attached on its dorsal surface but free ventrally. The forward continuation of the conus, the *bulbus aortae*, divides into right and left branches, each of which in turn gives rise to three trunks: the *carotid* arch, the *systemic* or *aortic* arch, and the *pulmo-cutaneous* arch. The aortic arches curve toward each other until

they meet in the midline somewhat posterior to the heart to form the single *dorsal aorta.* Branches are given off from the arches, and from the aorta to all parts of the body posterior to the head. The pulmo-cutaneous trunks carry venous blood to the lungs and skin respectively to be aerated. Venous blood

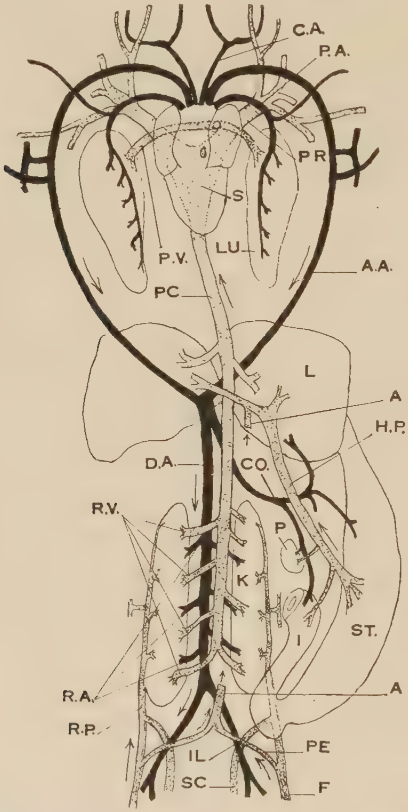


FIG. 70.—Diagram of the circulatory system of the frog from the ventral side. A, anterior abdominal vein; A.A., aortic arch; C.A., common carotid artery; CO., cœliac artery; D.A., dorsal aorta; F, femoral vein; IL, iliac artery; K, kidney; L, liver; LU, lung; P, pancreas; P.A., pulmonary artery; P.C., postcava; P.E., pelvic vein; PR, precaval vein; P.V., pulmonary vein; R.A., renal artery; R.P., renal portal vein; R.V., renal vein; S, sinus venosus; SC, sciatic vein; ST, stomach.

from the head and the anterior part of the body is returned to the sinous venosus by right and left *precaval* veins; from the posterior part by the single *postcava.*

Action of the Frog's Heart.—The contractions of the heart begin with the sinosus venosus, followed in order by the contrac-

tion of the right atrium, left atrium, and ventricle. The ventricular contraction follows the others so quickly that the arterial blood from the left atrium and the venous blood from the right do not have time to mix in the ventricle, as they are kept apart to a certain extent by the muscular *trabeculae* (ridges) of the ventricle. Since the conus leaves the heart on the right side, the first blood it receives on contraction of the ventricle is the venous blood from the right atrium. This enters the conus to the left of the longitudinal valve (*cavum pulmonale*) and is directed to

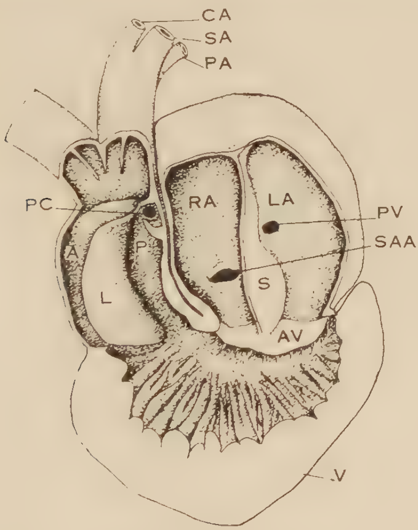


FIG. 71.—Frog's heart dissected from ventral side. A, cavum arteriale; AV, atrio-ventricular valve; CA, carotid arch; L. longitudinal valve of conus; LA, left atrium; P, cavum pulmone; PA, pulmo-cutaneous arch; PC, opening into pulmo-cutaneous arches; PV, opening of pulmonary vein; RA, right atrium; S, septum between atria; SA, systemic arch; SAA, opening of sinus into right atrium; V, ventricle.

the pulmo-cutaneous aperture. As soon as the cavum pulmone is filled, the following blood enters the conus on the other side of the valve (*cavum arteriale*). The first of this portion of blood is probably mixed venous and arterial, while the last of it is entirely pure. The first portion on reaching the bulbus enters the large openings of the aortic trunk, while the last enters the carotid trunks, the greater resistance of the latter accounting for the filling of the aortic trunks first. The result is that the head and brain receive the purest supply of blood, while the rest

of the body, supplied by the systemic aorta, receives slightly contaminated blood.[1]

The frog has both a hepatic portal and a renal portal circulation. In connection with the latter it may be noted that the venous blood from the hind legs passes in part through the kidneys *via* the renal portal veins, and in part through the liver *via* the anterior abdominal vein.

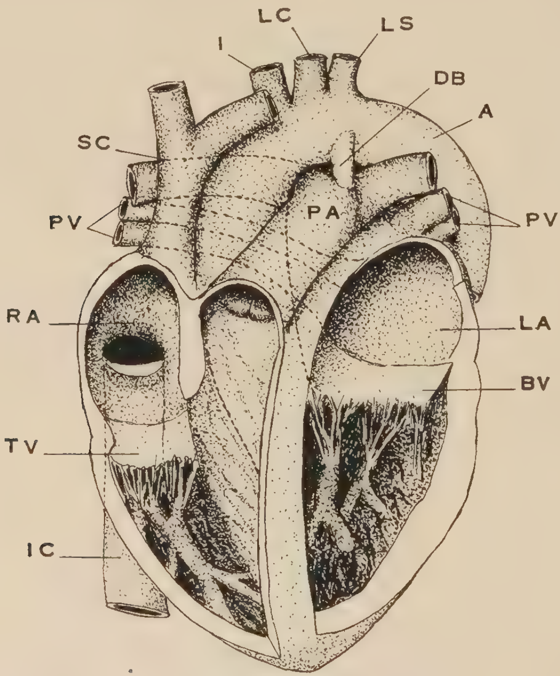


FIG. 72.—Human heart dissected from the ventral side, diagrammatic. A, aorta; BV, bicuspid valve; DB, Ductus Botalli, a solid cord, which in the embryo is a blood vessel connecting the pulmonary artery with the aorta; I, innominate vein; IC, inferior cava (postcava); LA, left auricle; LC, left carotid artery; LS, left subclavian vein; PA, pulmonary aorta which divides into right and left pulmonary arteries; PV, pulmonary veins; RA, right auricle; SC, superior cava; TV, tricuspid valve.

Mammals.—The mammalian heart consists of *four chambers:* two atria, or auricles, and two ventricles, making possible a completely *double circulation.* A sinus vensus is not present in the adult. In the fish the heart cavities contain only venous

[1] This account of the action of the frog's heart, which follows that given in Parker & Haswell's Textbook of Zoology, has been verified, to the author's satisfaction at least, by injection experiments, careful dissections, and a reconstruction of the conus.

blood; in the frog the right atrium contains venous blood, the left atrium arterial blood, while the ventricle contains both kinds imperfectly separated; in the mammal the right side of the heart carries only venous blood while the left side carries arterial. Each atrium is connected with the ventricle of the same side by an opening guarded by valves which allow the blood to pass from atrium to ventricle, but not in the reverse direction. The ventricles have much thicker walls than the atria and the left ventricle is much larger than the right. The inner walls of the atria are smooth, while those of the ventricles are raised into thick muscular ridges. The *atrio-ventricular valves* are thin, tough flaps, three *tricuspid* on the right and two *bicuspid* on the left side of the heart. The free edges of the valves are held in place by thin tendinous threads attached by thick *muscular pillars* to the walls (Fig. 72.) The contraction of the muscular pillars exerts a steady tension on the tendons, keeping the valves closed during ventricular contraction of the ventricle. Venous blood is returned from the head and anterior parts of the body by a single *superior vena cava* that enters the right atrium; from the posterior part of the body by the *inferior vena cava*, whose entrance into the right atrium is guarded by a large flap-like valve. The large veins of the extremities are provided with cup-like valves that allow the blood to flow toward the heart but not away from it. From the right atrium venous blood passes into the right ventricle, whence it is pumped through the *pulmonary artery* to the lungs. Backflow is prevented by a set of three semilunar valves located in the artery but just beyond the ventricle. The pure, aerated blood is returned from the lungs by the *pulmonary veins* to the left atrium, from which it passes through the atrioventricular aperture into the left ventricle. The latter then pumps it through the *aorta* to all parts of the body. The aorta, like the pulmonary artery, contains three semilunar valves that prevent

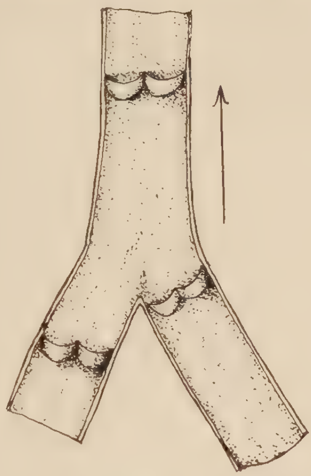


FIG. 73.—Diagram to show the position of the cup-like valves in an opened vein spread out flat. The arrow shows the direction of blood-flow.

back flow. Mammals have a hepatic portal circulation, but no renal portal system.

Blood.—Consisting of a viscous fluid, *plasma*, in which *corpuscles* are suspended, blood may be regarded as a *fluid tissue.* The color of the blood of invertebrates is due to pigment, or, more properly, a *chromoprotein*, dissolved in the plasma. Thus, the pale-blue color of the blood of the crab is due to the presence

FIG. 74.—Group of red corpuscles and two leucocytes (L) as seen in a fresh human blood preparation. × 900.

of *hemocyanin* in its plasma, while the red color of the earthworm's blood is caused by *hemoglobin*. Each of these substances is concerned with the carrying of oxygen to the tissues. They have the power of uniting with molecular oxygen and giving it off in molecular form. When united with oxygen, *oxyhemocyanin*, as it is called, gives the blood a deep-blue color, while the *oxyhemoglobin* imparts a rich scarlet shade to the blood; when reduced,

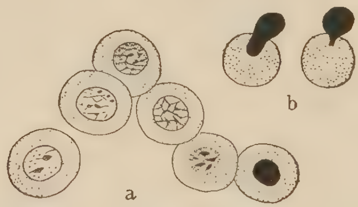


FIG. 75.—The development of red corpuscles in cat embryos. a, successive stages in the development of a normoblast; b, the extrusion of the nucleus. (*From Stöhr, Textbook of Histology, by Lewis. P. Blakiston's Son & Co. By permission.*)

i.e., its oxygen removed, hemocyanin is pale-blue and hemoglobin is purple. The corpuscles of the invertebrate blood are generally pigment-free cells having amœboid movement.

The plasma of the vertebrate blood when separated from the corpuscles by the centrifuge appears as a clear, straw-colored liquid. It is composed of about 90 per cent water and various organic and inorganic constituents. Among the organic consti-

tuents are three blood proteins, *serum globulin*, *serum albumin*, and *fibrinogen*. The *corpuscles* are of various kinds: (1) *red corpuscles* (erythrocytes), (2) *white corpuscles* (leucocytes), and (3) *blood platelets*. The red corpuscles contain hemoglobin, which gives the blood its characteristic red color. In all vertebrates below mammals these cells are nucleated discs, usually having an elliptic outline, with the center bulged out by the nucleus. The red cells of mammals are non-nucleated, biconcave, circular discs, except in the llama and camal groups, where they are oval. Nuclei are present in embryonic mammalian red cells, but are lost in later development. The accompanying table gives an idea of the relative size and abundance of the red cells in the various groups. In man, at least, and probably in other mammals, too, the number varies with altitude above sea level.

TABLE I

		Per Cubic Millimeter of Blood
Man	7.2–7.8μ	5,000,000
Monkey	7.0	6,355,000
Guinea pig	7.48	5,859,000
Dog	7.2	6,650,000
Cat	6.2	9,900,000
Horse	5.58	7,403,500
Musk deer	2.5	
Dove	14.7 × 6.5	2,010,000
Tortoise	21.2 × 12.45	629,000
Frog	22.3 × 15.7	393,000
Carp	17.7 × 10.1	

From HUBER, BÖHM, DAVIDOFF, "Textbook of Histology," *W. B. Saunders Company. After Rollett and Bethe.*

The white cells or leucocytes contain no hemoglobin, but are nucleated and often show amœboid movement. In man their size varies form 5 to 12μ; in numbers they occur in the blood in about the proportion of 1 to 300 to 500 red cells. They are not all alike, and are ordinarily classified as follows: (1) *small* and *large lymphocytes*, forming 20 per cent of the entire number; (2) *mononuclear leucocytes*, 2 to 4 per cent; *transitional leucocytes*, 2 to 4 per cent; and (4) *polymorphonuclear*, or *polynuclear*, *leucocytes*, 70 per cent. Leucocytes have been observed creeping through the walls of capillaries, *diapedesis*, and penetrating between tissue cells. Their function in part at least, is to absorb superfluous tissue particles and foreign bodies, such as bacteria.

Carrel and others have found that serum alone will not support the growth of epithelial or connective tissue cells in tissue cultures; that either embryonic tissue juices or leucocytes must be present for growth to proceed. This suggests that leucocytes contain growth-promoting substances or that they have the power to transform serum so that it can be utilized as nutrition by the cells under cultivation. In the body, leucocytes may also have this function of acting as intermediate agents between cells and substances in the blood.

Fig. 76.—Blood plates beside a red corpuscle. From "Stöhr's Textbook of Histology" by Lewis. P. Blakiston's Sons & Co. By permission.

Blood platelets are cells of the blood having a circular or irregular outline, measuring from 2 to 4μ in diameter, and containing a centrally located group of granules, suggesting a nuclear component. They seem to be active agents in the *clotting* of blood; for, when clotting occurs, *fibrin*, the fibrous framework of the clot, is deposited in slender threads that radiate from disintegrating blood plates.

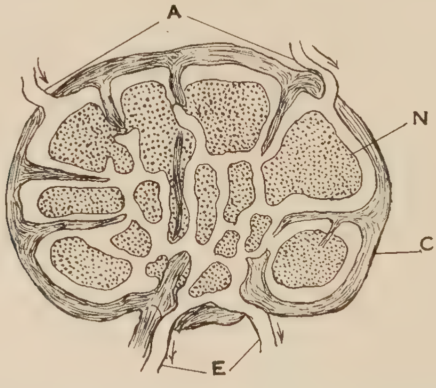


Fig. 77.—Diagram of a lymph gland. A, afferent lymph vessels; C, capsule, from which trabeculae extend inward; E, efferent lymph vessels; N, nodule, composed mostly of lymphocytes. (*Modified after Stöhr.*)

Lymph.—In invertebrates, the lymph, blood, and body fluid are in many cases the same, but in vertebrates *lymph* is distinct from blood and is carried for a part of its circulation by separate vessels called *lymphatic vessels*. The latter differ from blood vessels in two respects: (1) their walls are much more delicate in structure, and (2) their free passage is interrupted from time to time by *lymph glands*, which are nodules of various sizes composed largely of lymphocytes enclosed in a capsule, through which the lymph slowly filters. In lower vertebrates

(frog, etc.) pulsating portions, called lymph hearts, occur in the vessels. The system begins in lymph capillaries in the tissues, which unite to form larger vessels that eventually tap the veins, especially the large veins near the heart. The flow of lymph is from peripheral parts toward the heart, and is brought about in part by contractions of lymph hearts and in part by the movements of the body muscles compressing the vessels. Lymphatic vessels are provided with *valves*, similar to those in the long veins, which allow the lymph to be squeezed past them toward

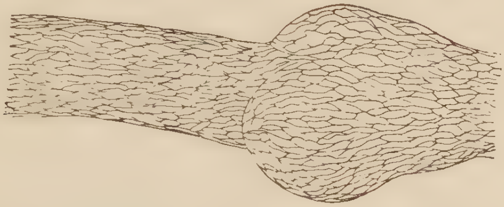


FIG. 78.—Silver nitrate preparation of a lymphatic vessel from a rabbit's mesentery, showing the boundaries of the endothelial cells and a bulging just beyond a valve. (*From Stöhr's Textbook of Histology, by Lewis. P. Blakiston's Son & Co. By permission.*)

the heart, but not in the reverse direction. Lymph hearts are absent in the higher vertebrates.

Lymph is a fluid closely resembling blood, except that it is colorless. It consists of *plasma* and *corpuscles*, of which *lymphocytes* form the largest part. Red cells and polymorphonuclear leucocytes are absent. Since the lymph plasma is doubtless replenished from the blood by diffusion through the capillary walls, the probable function of the lymph is to carry nutriment from the blood to the tissues and to remove metabolic products from them.

CHAPTER VIII

ORGANS OF EXCRETION

An unavoidable result of metabolism in animals is the produc tions of *end-products* which are not only of no further value to the body as a source of energy, but may be a distinct menace to the life of the organism because of their toxic properties. Such substances, called *excretory* products, are removed by excretory organs of a special sort, as well as by the gills or lungs, the integument, and the alimentary canal. Obviously, a number of organs take part in excretion, but the term *excretory organ* ordinarily refers to that organ whose sole function is excretion, as, for example, the *kidney*.

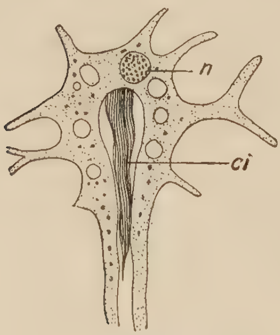


Fig. 79.—Flame cell of a protonephridium of a flatworm. *ci*, cilia within the funnel-shaped cavity of flame-cell; *n*, nucleus. (*From Hesse and Doflein after Lang.*)

Flame Cells.—In an animal like the flatworm, *Planaria*, the excretory system is composed of canals beginning in innumerable capillaries whose blind ends are formed of single cells called flame cells. The flame cell is irregular in outline and bears a bundle of *cilia* extending into the end of the capillary. The flickering movement of the cilia is like that of a flame. The irregular projections of the flame cell beyond the capillary penetrate the surrounding tissues. Leaving the flame cells, the capillaries unite to form larger tubes, which eventually open by an excretory pore on the surface of the body. Excretory products are absorbed from the tissues through the flame cell and the walls of the capillaries, and are propelled to the outside by the vibrations of the cilia. Such an excretory organ is known as a *protonephridial* system.

Nephridia.—The excretory system of the earthworm is an example of a nephridial system. The presence of a distinct body cavity and a well-developed circulatory system has an important

bearing upon the method of excretion and the character of the excretory organ. The body cavity of the earthworm is a space between the body wall and the alimentary canal, divided by a series of compartments by transverse septa, *dissepimenta*, extending from the body wall to the intestine, and corresponding in position to the external annular grooves. The cavities of the body are filled with a colorless fluid or lymph, containing corpuscles; and each cavity after the first four is provided with a pair of

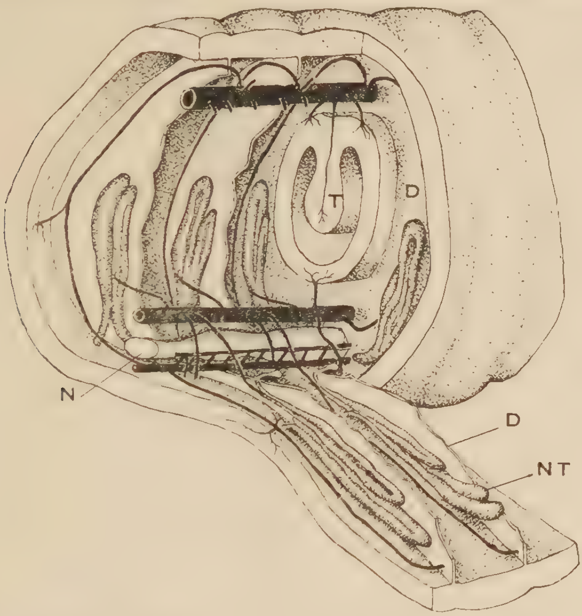


Fig. 80.—Stereogram showing the relations of organs in posterior segments of earthworm. The anterior end is to the right. A piece of the intestine has been removed and two dissepiments have been cut. Blood vessels are shown in black. The blood moves toward the anterior end (right) in the dorsal vessel and posteriorly in the subintestinal one. D, dissepiment; N, nerve cord; NT, nephridial tubule; T, typhlosole, a median longitudinal fold hanging from the dorsal wall of the intestine. (*After McGregor and Calkins.*)

nephridial tubules, one on each side. Each tube or nephridium consists of the following regions: (1) a ciliated *nephrostome*, (2) a ciliated *neck*, (3) a coiled *narrow tube*, (4) a wide *glandular tube*, and (5) an *ejaculatory duct* opening to the outside by the *nephropore*. The nephrostome, provided with a slit-like opening, projects through the anterior wall of the compartment in which it lies into the next compartment, whence it removes excretory matter. When powdered carmine is injected into the body cavity it is

absorbed by the *chlorogogue* cells, which are large yellowish-brown cells forming the outer covering of the intestine. These cells then disintegrate, freeing the carmine and cell fragments; all of which are finally swept in the current caused by the motion of the cilia of the nephrostome through the nephridium to the outside (Calkins). The glandular part of the nephridium is richly supplied with blood vessels, from which it is assumed that the blood loses metabolic products in passing through the capillary network about the tubule. Thus it would appear that excretory products are removed at two points: (1) by the chloro-

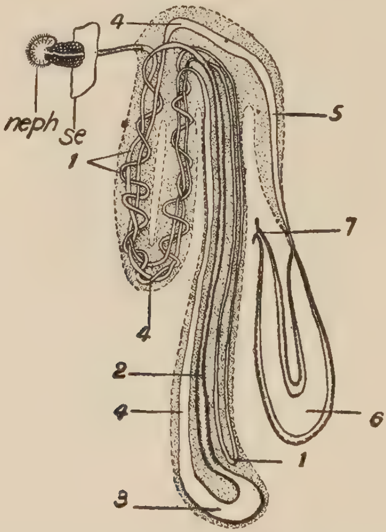


FIG. 81.—Nephridium of earthworm, schematic, *neph*, nephrostome; *se*, portion of septum: 1–6, parts of tubule; 7, nephrostome. (*From Hesse and Doflein after Maziarski.*)

gogue cells first absorbing excretory products from the body fluid, and then breaking down, the fragments passing out through the nephrostomes; and (2) by the cells of the tube, especially the glandular part, absorbing products from the blood stream.

Malpighian Tubes.—In insects the excretory organs are the Malpighian tubes, a clump of fine, hair-like tubules attached to the alimentary canal at the beginning of the intestine, and projecting into the hemocœl. They are blind at their distal free ends and open proximally into the alimentary canal. Excretory products are absorbed from the body fluid or blood and then carried through

the tubes to the intestine, whence they pass out of the body with the feces.

Kidney.—The excretory organ of vertebrates is the kidney and it would seem to be derived from a type resembling the nephridial tubule of the earthworm. There are three distinct stages in the development of the kidney, known as the *pronephros*, the *mesonephros* and the *metanephros*. The pronephros is the first stage in the embryonic development of the excretory organ in all except the highest vertebrates and is the adult stage in the lowest vertebrates (*Cyclostomata*). It consists of segmentally

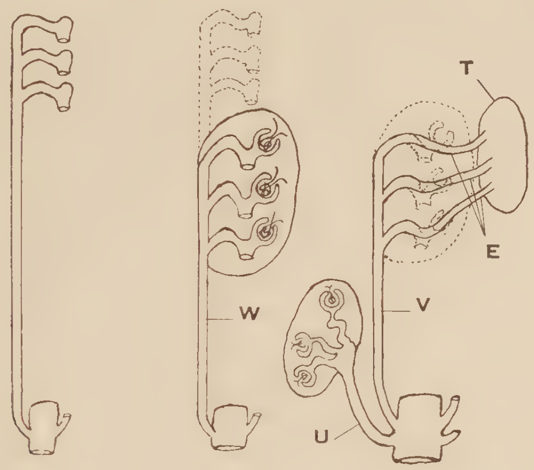


FIG. 82.—Diagram of three stages in the development of the vertebrate kidney. A, pronephros; B, mesonephros; C, metanephros (male). E, vasa efferentia; T, testis; U, ureter; V, vas deferens; W, Wolffian duct.

arranged nephridial tubules whose nephrostomes open into the body cavity but whose nephropores, instead of having separate outside openings, are united to form a *pronephric* duct, one on each side, which passes back and enters the cloaca (Fig. 82). In the embryo of higher vertebrates the pronephros disappears and is succeeded by the mesonephros, which arises at a more posterior level. This organ is also composed of tubules, connected with a duct known as the *Wolffian duct* (pronephric duct). Near the nephrostome, each tubule is invaginated to form a double-walled cup, the *capsule*, into which a capillary network of blood vessels, the *glomerulus*, projects. The capsule and

glomerulus constitutes a *Malpighian Corpuscle.* The mesonephros is the adult kidney of fishes and amphibians. In the male of both of these some of the mesonephric tubules are utilized to serve as ducts, *vasa efferentia,* to convey spermatozoa from the testis to the Wolffian duct. In the female the Wolffian duct is an excretory duct only.

In *reptiles, birds,* and *mammals* the mesonephros is an embryonic organ only, while the metanephros which develops later and caudad to it becomes the adult kidney. The mesonephros persists partially in the male as the vasa efferentia, which are

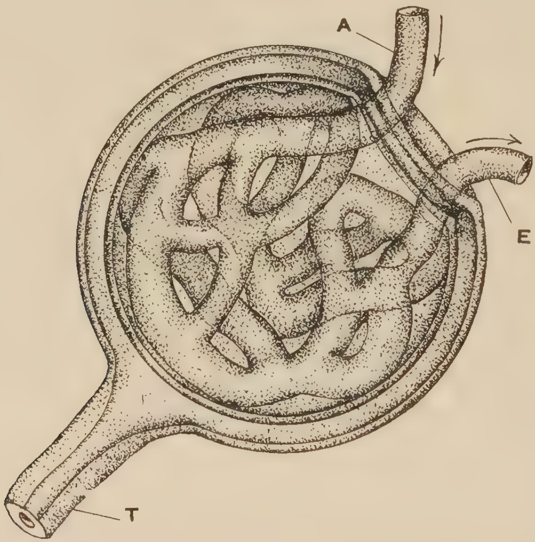


FIG. 83.—Diagram of Malpighian corpuscle, highly magnified. A, afferent artery; E, efferent artery; T, tubule. The arrows show the direction of blood-flow.

modified mesonephric tubules and which join the Wolffian duct, now known as the *vas deferens.* The metanephric tubules resemble those of the mesonephros except that they lack nephrostomes opening into the body cavity. The *ureter* develops as an outgrowth from the posterior end of the Wolffian duct, but later comes to have a separate opening into the cloaca. It is expanded to form the *pelvis,* where it joins the metanephros.

In the adult, the fully developed metanephros, especially in mammals, shows very little evidence of segmentation. In man, the kidney is a compact bean-shaped organ, lying one on either side against the dorsal wall of the body cavity, and covered by

the peritoneum. The concavity in the middle of the kidney on its medial side is the pelvis, from which the ureter carries the excretory product, *urine*, to the *bladder*. The latter is a large sac-like vesicle lying in the lower part of the abdominal cavity against the abdominal wall. A single duct, the *urethra*, leads to the outside.

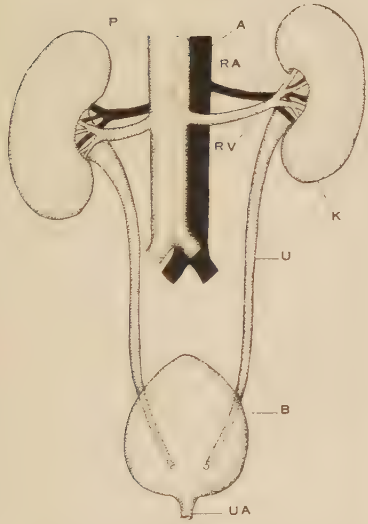


FIG. 84.

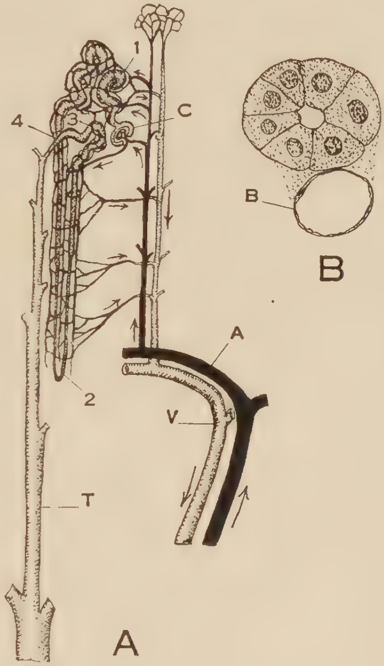


FIG. 85.

FIG. 84.—Excretory organ of man, diagrammatic. A, aorta; B, urinary bladder; K, kidney (left); P, postcava; RA, renal artery (left); RV, renal vein (left); U, ureter (left); extends from the pelvis of kidney to the base of bladder; UA, urethra, a canal to the outside.

FIG. 85.—A. Diagram to show the relations between the blood vessels and the nephridial tubules of the human kidney. A, artery; C, Malpighian corpuscle; 1–4, parts of tubule; T, straight collecting tubule which leads to the pelvis of the kidney; V, vein. The arrows indicate the direction of blood-flow. B, section of the thick portion of a loop of Henle to show its relation to the blood capillary (B). (*Modified from Stöhr.*)

Microscopic examination shows that the kidney is made up of a complicated mass of nephridia-like tubules having a peculiar relation to the blood system. The dorsal aorta sends to each kidney a *renal* artery, which soon breaks up into smaller branches in the kidney. Some of these arterioles end in ordinary capil-

laries, while others form Malpighian corpuscles with the tubules. The blood enters the glomerulus by an *afferent* artery and leaves by an *efferent* artery, so that the glomerulus might be regarded as a complicated knot in the course of the arteriole. The capsule at the dilated end of the tubule into which the glomerulus projects is a double-walled cup, the inner wall of which is closely applied to the glomerulus, while the outer wall forms the beginning of a uriniferous tubule. The latter consists of the following parts: (1) the *proximal convoluted* portion; (2) a U-shaped part consisting of *straight ascending* and *descending loops of Henle;* (3) the *distal convoluted* portion; and (4) the *arched collecting* portion, from the confluence of a number of which the *straight collecting* tubules are formed. The latter empty into the pelvis of the kidney, which is really the expanded end of the beginning of the ureter. The efferent vessels leaving the glomerulus are distributed among the tubules, from the capillary net work of which veins lead the blood to the renal vein.

There are two places where the blood is freed of excretory products in the course of its circulation through the kidney, namely: (1) in passing through the glomeruli, where principally water is lost, and (2) in passing through the capillary network about the tubules where solids in solution are first absorbed from the blood by the cells of the tubules, and then excreted by the cells of the latter into the lumen of the tubules.

It should be clear from what has been said that the organ of excretion, whether gill, lung, skin, or kidney, is merely a means of ridding the animal body of waste matter. The circulatory fluid acts as a vehicle for conveying the excretory products formed by every cell in the body to some point where they can be eliminated. The excretory organ is the *eliminator.* In mammals the kidney is a huge gland whose cells are capable of extracting metabolic products from the blood and then secreting them into the cavities of the tubes whose walls these cells form. The excretory organs are like sieves which filter out the excretory content of the body fluids.

CHAPTER IX

ORGANS OF REPRODUCTION

An organism is in many ways comparable to a machine, but organic reproduction is not so much like the construction of a machine out of raw materials or from ready-made parts as the gradual growth of and development of a part of an old machine. Reproduction of a living thing begins with the *separation* from the parent of a part of its body which is alive from the start and continues to live as it advances through developmental stages to the adult condition. The developing part is a *functioning organism* from the very beginning, whereas a machine does not function until all its parts are completely formed and properly assembled.

The final act in the reproduction of a protozoan is the division of the cell into two parts. In higher animals development of a new individual starts in an *egg*, which is usually *fertilized* by a *spermatozoön*, but here also reproduction is, fundamentally, a matter of *division*, since each reproductive element is derived from a cell of the parent body by a process of cell division.

Gonads.—The ovary and the testis are the *gonads* or organs of reproduction. *Monœcious* or *hermaphroditic* animals (many invertebrates) are unisexual and have both ovary and testis in the same individual while *diœcious* animals are bisexual, the ovaries being present in the female and the testes in the male. The germ cells or *gametes* are the cellular products of the gonads, the ovary producing eggs or *ova*, the testis *spermatozoa*. *Fertilization* consists in the union of ovum with spermatozoön to form the *oösperm* or fertilized egg or *zygote* from which a new individual develops. This method of reproduction is known as *amphigony*. *Parthenogenesis* is a method of reproduction occurring in some animals in which the egg develops without the intervention of a spermatozoön. In *oviparous* animals the young hatch from eggs laid by the female, while in *viviparous* forms the young are born alive.

Agamic Reproduction.—*Sexual* or *gamic* reproduction is reproduction from an egg whether fertilized or not. It occurs in all metazoans, but in some of the invertebrates, in addition, another method of reproduction is found, known as *asexual* or *agamic*, such as *fission* or *budding*. Thus, *Hydra*, a monœcious animal, reproducing sexually, also at times undergoes fission or budding. Fission takes place by a longitudinal splitting beginning at the distal end and extending down through the pedal disc, or by a transverse constriction across the middle of the body, the result in either case being two complete but smaller individuals. Budding begins with the formation of a bulge in the body wall, which later pushes out and develops a circlet of tentacles at its distal end. When fully grown, the bud is detached as a new and free individual. *Planaria* is another common laboratory animal in which fission takes place, although gamic reproduction also occurs.

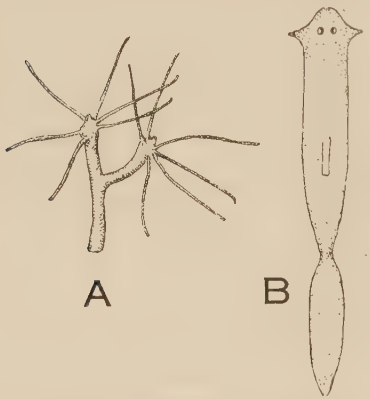


Fig. 86.—A, fission in Hydra by longitudinal divison. (*After Koelitz.*) B, fission in Planaria. (*After Child.*)

Gamic Reproduction.—In simple organisms, like Hydra, for example, when gamic reproduction occurs, the eggs and the sperm are freed by rupture of the enclosing body wall (see Fig. 178), but in more complex animals, in which the gonads are located internally, ducts and other accessory structures are present for bringing the germ cells together, or for conveying them outside the body either before or after fertilization. In the female a pair of *oviducts*, one for each ovary, provides a passage for the eggs to the outside, and secretes the egg envelopes. In viviparous animals a part of the oviduct is modified into a *uterus*, in which the embryo develops until birth. Similarly, in the male each of the testes is provided with a *vas deferens* for conveying the sperm to the outside. In the male there is also a *penis*, an intromittent organ for introducing sperm into the body of the female, in those cases where fertilization is internal. This occurs in all viviparous animals and in many oviparous forms as well. As far as development is concerned, the difference between oviparous and viviparous forms consists in the fact

that in the former a portion of embryonic development takes place in the egg after it is laid, whereas in the latter all of the embryonic period is completed before birth.

In *segmented worms* and in all *vertebrates* there is a close relationship between the accessory parts of the reproductive system and the excretory system, both in the embryonic and adult condition. Thus, the vas deferens of the vertebrates is a modified Wolffian duct, and some of the tubules of the testis are derived from nephridial tubules.

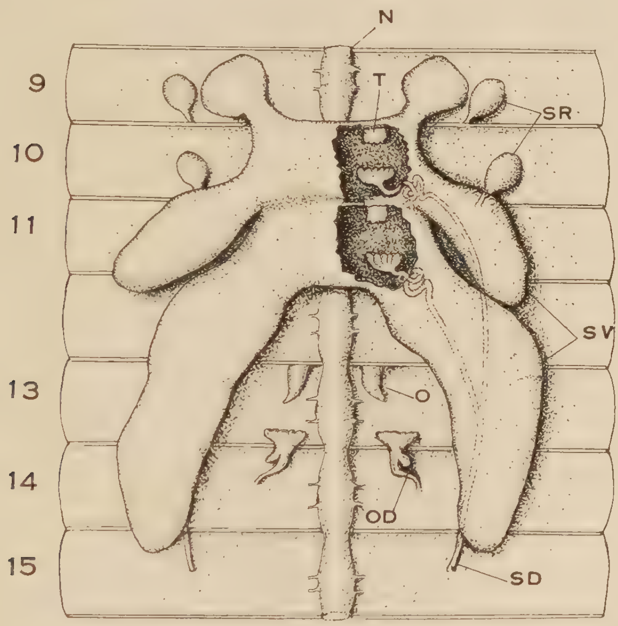


FIG. 87.—Diagram of the reproductive organs of earthworm. N, nerve cord; O, ovary; OD, oviduct; SD, sperm-duct (vas deferens); SR, sperm-receptacles; SV, sperm-vesicle, with part of the roof removed to show the testes, T, and the funnels of the sperm-ducts.

Reproduction in Hermaphroditic Forms. In the *earthworm*, the oviducts and the sperm ducts are modified nephridial tubules. The *testes* consist of two pairs of organs lying in the body cavity, one pair on the posterior side of the anterior wall of the *tenth* segment and the other pair in a similar position on the anterior wall of the *eleventh* segment. The testes and parts of the cavities in which they lie are enclosed in a large sac, the *seminal vesicle*, which is drawn out into three lobes on each side.

When the sperm cells reach a certain stage in their development, they are detached from the testes and become free cells in seminal vesicles, where development is completed. The spermatozoa finally leave the seminal vesicle through four ciliated openings (modified nephrostomes) situated one opposite each testis on the posterior wall of the segment. The ducts from the two ciliated funnels on each side unite to form a vas deferens which opens externally on the *fifteenth* segment.

Fig. 88.—Copulation in *Helodrilus fœtidus*. (*After Foot.*)

The *ovaries* of the earthworm are two in number and are situated on the posterior surface of the anterior wall of the *thirteenth* segment. As the eggs mature, they burst from the ovary and are conveyed to the outside through a pair of oviducts, each of which begins with a funnel-shaped opening in the posterior wall of the *thirteenth* segment and terminates in an opening on the outside of the *fourteenth*. The *seminal receptacles* are two pairs of sacs in the *ninth* and *tenth* segments, opening only to the outside. At the reproductive period these sacs are filled with

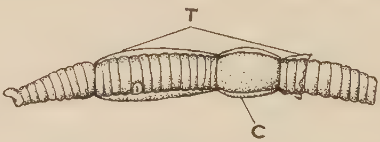


Fig. 89.—The formation of a slime-tube by a single worm at some period after copulation. c, cocoon formed about the clitellum; t, slime tube. (*After Foot and Strobell.*)

sperm from another worm and remain until the eggs are deposited, when they are emitted from the sacs to fertilize the eggs.

According to the observations of Foot on the earthworm, *Helodrilus fœtidus*, two individuals pair at copulation with the ventral surfaces opposed and with the openings of the vasa deferentia of one opposite the *clitellum* of the other (Fig. 88). The clitellum, a swelling in the body composed of several segments, then secretes a *slime tube* about the body of each worm, binding them together. A similar slime tube may be formed by a single worm at intervals after copulation (Fig. 89). The slime tube closely follows the outlines of the worm's body, being enlarged

in the region of the clitellum to form the *cocoon*. During copulation the spermatozoa of one individual are discharged into the cocoon of the other and then find their way to the sperm receptacles, where they are stored. The worms then separate, but, while the slime tubes are still in place, eggs are discharged from the oviducts and pass into the cocoons. The worms now wriggle backward out of the slime tube and, as the cocoon passes the openings of the sperm receptacles, spermatozoa are discharged. The eggs are fertilized in the cocoons where development of the embryo takes place. As each worm withdraws from the tube, the end of the cocoon contracts forming a closed *capusle* (Fig. 90).

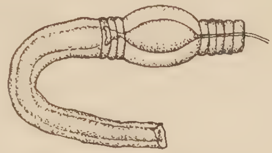


FIG. 90.—Appearance of slime-tube after shedding. (*After Foot.*)

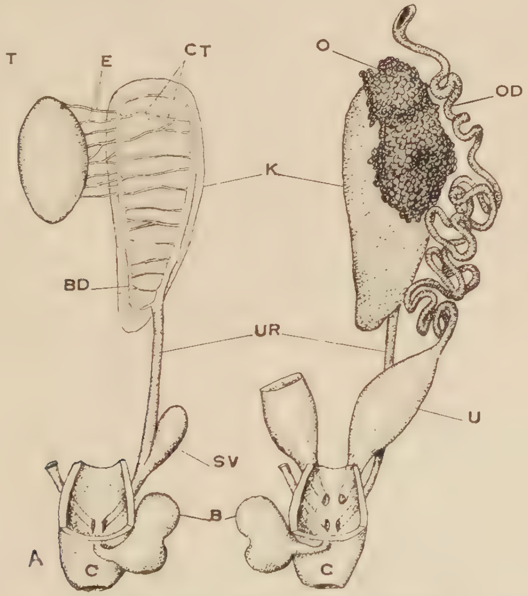


FIG. 91.—Diagram of urogenital organs of frog, left side; A, male; B, female. B, bladder; BD, Bidder's duct; C, cloaca, opened to show outlets of urogenital ducts and bladder in its dorsal wall; CT, collecting tubules of kidney, which also receive uriniferous tubules, not shown; *E*, vasa efferentia, through which sperm from testis reach Bidder's duct; K, kidney, shown in section in male; O, ovary; OD, oviduct, which eggs enter by funnel-shaped opening above; SV, seminal vesicle where sperm are stored; T, testis; U, uterus; where mature eggs are stored before deposition.

Bisexual Reproduction.—In the *frog* the testes are a pair of white ovoid bodies attached to the anteroventral border of the

kidneys. From the inner edge of each testis a number of fine tubes, the *vasa efferentia,* pass into the kidney and open into a longitudinal canal called *Bidder's duct.* From the latter, collecting tubules lead to the ureter lying in the outer margin of the kidney. *Uriniferous* tubules also open into the collecting tubules. Spermatozoa pass from the testis through the vasa efferentia and collecting tubules to the ureter. In the outer edge of the latter near its termination in the cloaca is an enlargement, the *seminal vesicle,* where spermatozoa are stored.

In the *female* a pair of ovaries having a lobulated appearance are suspended from the dorsal body wall by a mesovarium and overlie the kidneys. The two oviducts (*Mullerian ducts*) are convoluted tubes each having an opening or *ostium* at its narrow anterior end, and a widened region or uterus posteriorly where it enters the cloaca by a small opening. When the eggs are mature, they burst through the ovarian epithelium and enter the oviducts in the upper parts of which they receive an albuminous coating. The eggs accumulate in the uterus until they are laid.

In *copulation* the male clasps the female and sheds sperm over the eggs as they are expelled from the cloaca. After *impregnation* has been effected by a single sperm entering each egg, the albuminous envelope of the latter swells and forms a thick protective covering. Only a single sperm is necessary for fertilizing an egg.

From this it will be noted that in the male frog the ureter is a *urogenital* duct, but in the female a *urinary* duct only. The oviducts, the genital ducts of the female, are absent or degenerate in the male.

Intrauterine Development.—With the exception of the lowest group, the *Prototheria,* which are oviparous, all existing mammals bring forth their young alive. In these animals a means is provided for supplying the developing embryo with nutrition until it is born, after which it is nourished by the mammary glands of the mother. Viviparity, however, is not confined to mammals, but occurs in lower vertebrates and in some invertebrates as well; but what happens in these cases is that the large-yolked egg after fertilization remains in the special part of the oviduct known as the uterus, and develops there instead of outside of the body. In mammals, on the other hand, portions of the oviduct are modified into a uterus, which may be single or double, whose walls are highly vascular and come in close enough

FIG. 92.—Embryo sharks of a viviparous species, *Mustelus mustelus*, attached to the walls of the uterus. The expanded end of each umbilical cord forms a placenta-like structure, resembling that of mammals, through which the young are nourished. (*From Shull, LaRue and Ruthven, Animal Biology, after Fowler.*)

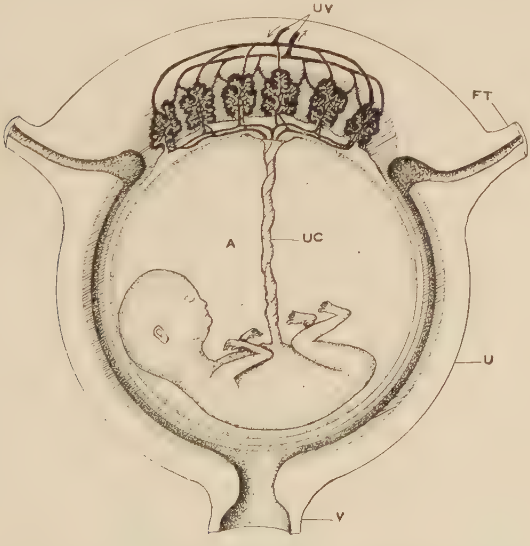


FIG. 93.—Diagram of posterior half of gravid human uterus. A, amniotic cavity, filled with fluid in which the fœtus (late embryo) rests; FT, Fallopian tube (oviduct); U, uterus; UC, umbilical cord, containing foetal arteries and veins through which blood circulates to and from the placenta, pumped by the fœtal heart; UV, uterine vessels, carrying maternal blood to and from the placenta; V, vagina. The shaded portions of the uterus are shed at birth.

contact with the tissues of the embryo to supply the embryonic blood with nutrition and to carry off excretory products. The maternal and embryonic blood streams are not confluent, however, for they are everywhere separated by the walls of their respective vessels. As a result, an organ known as the *placenta* develops during gestation, which consists of a maternal portion composed of the lining of the uterus and an embryonic portion of the embryonic tissues. The embryo is connected to the placenta by an *umbilical cord.* By this mechanism the small-yolked mammalian egg obtains sufficient nutrition from the mother to make development possible. In some mammals there is a separation at birth at the line between the maternal and the embryonic portions of the placenta, but in others, as in man, the entire placenta is shed. The portions of the uterine lining lost in *parturition* are restored by the remaining cells. The young are expelled by the contractions of the walls of the uterus. The *navel* is the place on the abdomen where the umbilical cord was attached during intrauterine development.

General.—The organs of reproduction, the ovary and the testis, as has been said before, are those producing germ cells, ova and spermatozoa, which, when united, are capable of reproducing a new animal. Both egg and sperm are merely detached portions of the parent body possessing the capacity, when brought together under proper conditions, of developing a new individual. In parthenogenesis the ovum alone can do this. Though a part of the body, the germ cells remain distinct from body cells and when favorable conditions arise for the union of ovum with sperm they proceed forthwith to display their remarkable developmental energy. Any other cell, such as muscle or liver cell, does not have this reproductive power, yet each, like the germ cell, has its origin in the fertilized egg. In becoming specialized body cells, it seems that the tissue cells lose the reproductive capacity, which must have been latent in them at the beginning. Germ cells, on the other hand, retain it because they do not differentiate into tissue cells. It would follow that once a cell has developed into a tissue cell it can never afterward function as a germ cell. This is true in most animals, there being some apparent exceptions among invertebrates like the *Cœlenterata,* where the germ cells develop from time to time from differentiated endoderm or ectoderm. Obviously, in such cases differentiation of body tissues even in the adult does not proceed so far that a return to an unspecialized state is impossible.

CHAPTER X

THE NERVOUS SYSTEM AND SENSE ORGANS

Stated in very general terms, the functions of the nervous system and sense organs are: (1) to bring about in the organism appropriate responses to external stimuli, and (2) to coordinate functional activity in different parts of the body. *Irritability* and *conductivity*, two properties manifested by all forms of protoplasm, are highly developed in nervous tissue, and all nervous phenomena are based primarily on these two fundamental attributes. Since Protozoa respond to the same stimuli which activate the nervous system of Metazoa, it is clear that the action of the nervous system as a coordinating mechanism in higher forms involves nothing new in principle. Nerve cells are to be regarded as cells that have become *especially* sensitive to stimulation of various sorts and that have also developed the capacity to conduct or transmit nervous impulses at a very rapid rate.

Neuron. The anatomical, and to a certain extent the functional, unit of the nervous system is the nerve cell or *neuron*. The size and the shape of the neuron vary greatly in different animals and in different parts of the same animal, but in all cases it consists of a *cell body* with *processes*. The processes can usually be classified both upon a structural and a functional basis into two groups: (1) *dendrons* or *dendrites*, consisting of one or more branching processes which carry nervous impulses toward the cell body; and (2) a single *axon* which carries impulses in the opposite direction. The neuron, as a whole, carries impulses in one direction only and is therefore said to be *polarized*. The term "nerve" refers to a bundle of axons or dendrons, or both, bound together by a connective-tissue sheath. An *afferent* or *sensory* nerve is one that conducts impulses from the periphery toward some centrally located nerve center, while an *efferent* or *motor* nerve transmits impulses in the opposite direction. The latter is called "motor" because the most common result following its stimulation is muscular contraction, which, in turn, produces motion. A *ganglion* is a mass of nervous tissue con-

sisting largely of cell bodies. The entire nervous system, including the sensory portions of the sense organs, is derived from the ectoderm, with the exception of taste cells, which in some cases at least are said to be endodermal in origin. In the following paragraphs some of the principal types of nervous systems occurring in different animal groups are considered.

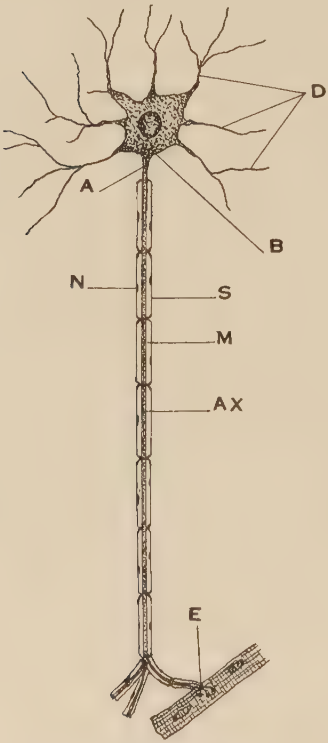


FIG. 94.—Diagram of a vertebrate motor neuron with a medullated axon. A, axon; AX, axis cylinder; B, cell-body; D, dendrons; E, motor end-organ in contact with muscle cells; M, myelin sheath; N, nucleus of sheath cell; S, one of the cells forming a sheath enclosing the myelin.

Diffuse Type.—A primitive form of nervous system is found in *Hydra* and related forms. It consists of nerve cells with branching processes forming a network, showing no tendency to be concentrated at any point into nerve centers or ganglia. In the evolution of this type of nervous system it may be assumed that as a result of external stimulation some ectodermal cells developed a nervous function to a greater degree than others, and as a result became specialized for this purpose. The nerve cells of Hydra did not, however, migrate very far from their site of origin but remained practically at the surface of the body.

Primitive Ganglionic Type.—In the flatworms, *Plathelminthes*, there is a considerable advance in the nervous system over the diffuse type, which is correlated with a greater structural complexity that cannot be served by a superficial nervous network. The nervous system of *Planaria* consists of a well-defined *cephalic ganglion* and a pair of *nerve cords* extending the length of the body. This constitutes the *central nervous system*, from which nerves extend, connecting it with the periphery. The nervous system is embedded in the tissues, which affords the utmost protection. (See Fig. 42.)

Ganglionic Type.—A further elaboration of the preceding type is the sort of nervous system found in a large number of invertebrates, such as segmented worms (*Annelida*), molluscs (*Mollusca*) and *Arthropoda*. It is characterized by the presence

A B

FIG. 95.—Nervous mechanism of Hydra. *A*, neuromuscular cell from ectoderm; *B*, ectodermal nerve pléxus. The long fibrils in the background are the contractile parts of neuromuscular cells. They lie in the mesoglœa. (*From Schneider.*)

of two or more ganglia from which afferent and efferent processes extend.

In the *earthworm*, for example, there is a fused pair of *supraœsophageal* ganglia, connected by a nerve cord or *commissure*

FIG. 96.—The nervous system of earthworm, diagrammatic. C, nerve commissure encircling œsophagus; I, infraœsophageal ganglion; S, supraœsophageal ganglion.

encircling the œsophagus with a similar *infraœsophageal* ganglion. From the latter a ventral *ganglionated nerve cord* extends the length of the body. The number and the arrangement of the ganglia in animals having this type of nervous system

depend upon the character of the body segmentation. In the earthworm the segmentation is *homonomous*, which means that it

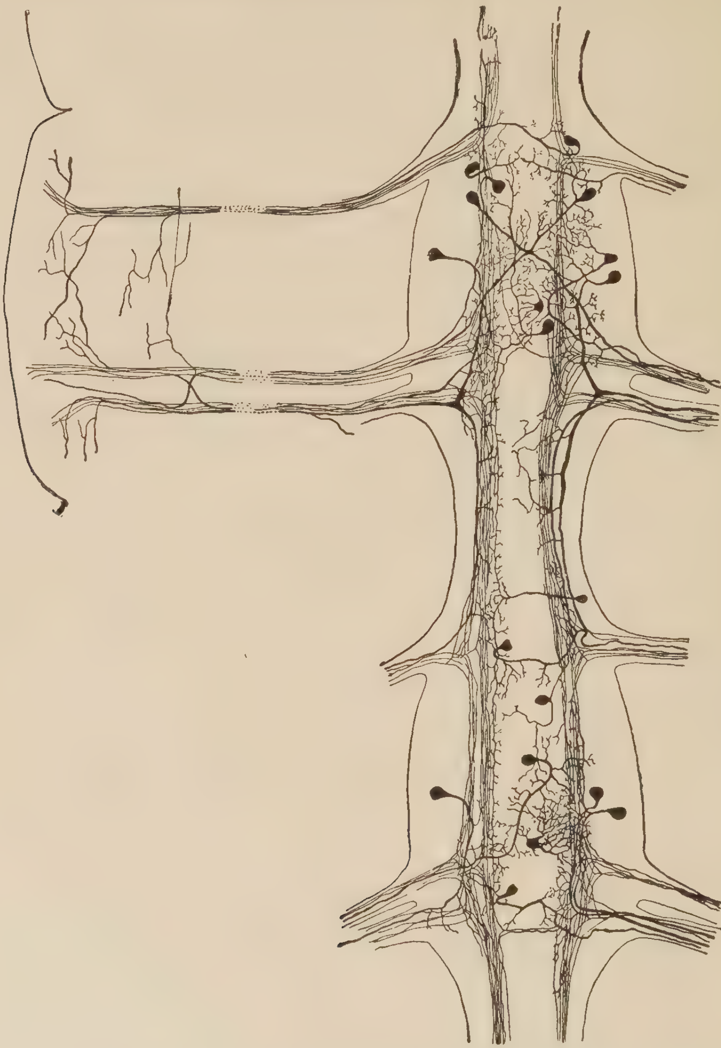


Fig. 97.—Portion of ventral cord of the earthworm with two ganglia and six pairs of lateral nerves. The sensory nerves end in terminal branches which connect with the dendrites of the motor and coordinating nerve cells of the cord. (*From Calkins, Biology, H. Holt & Co., after Retzius. By permission.*)

is characterized by a similarity in the size and structure of the segments. Accordingly, the ventral ganglia are similar in size

and large in number to correspond with the large number of body segments. On the other hand, in *arthropods* the segmentation is usually *heteronomous*, owing to the unequal size of the segments—the larger segments being formed by the fusion of two or more primitive segments. In such cases the ventral nerve ganglia are also reduced in number and vary in size. Thus, in the *grasshopper* the head contains both a supra- and an infra-œsophageal ganglion, the thorax three ventral ganglia, and the abdomen five. All the ventral ganglia are connected by a nerve cord which is double in the thorax and single in the abdomen. Nerves connect this central nervous system with the peripheral regions of the body and with sense organs. (Fig. 43.)

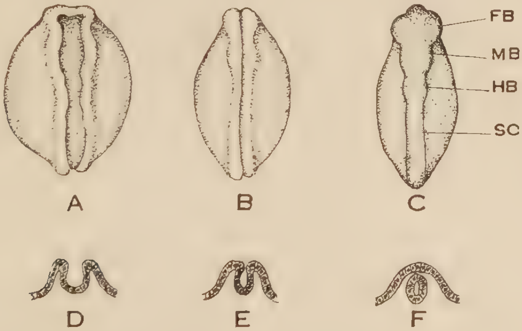


Fig. 98.—Three stages in the development of the nervous system of the salamander, *Amblystoma*. A, dorsal view of the embryo with open neural folds; B, edges of neural folds meeting in the midline; C, neural tube completely formed; D, cross section of open neural folds; E, cross section of closing neural folds; F, cross section of spinal cord of C, showing the cord as a tube pinched off from the ectoderm which has re-united above. FB, forebrain; HB, hind-brain; MB, midbrain; SC, spinal cord.

Tubular Type.—The *vertebrate* nervous system is known as the tubular type, because the brain and the spinal cord develop in the embryo from an ectodermal tube formed in the middorsal line. The walls of the anterior end of this tube thicken and differentiate into the embryonic *fore-*, *mid-*, and *hind-brain*, while the remainder retains a more tubular character and forms the *spinal cord.* The *gray matter* of the brain and cord is composed largely of cell bodies whose nerve processes form the *white matter.* The color of the latter is due to the fact that most of the fibers in the white zone are each enclosed in a white fatty *myelin sheath.* *Non-medullated* nerve fibers lack myelin and are gray in appearance.

Brain and Spinal Cord.—The three primary divisions of the embryonic brain develop into the adult vertebrate brain, which consists of five regions as follows: (1) the *telencephalon*, composed of paired lobes, the *cerebral hemispheres*, which are dorsolateral outgrowths of the forebrain; (2) the *diencephalon* or *twixtbrain*, forming the remainder of the forebrain; (3) the *mesencephalon*, whose walls form the *optic lobes*, and which represents all of the embryonic midbrain; (4) the *metencephalon* or *cerebellum*, a dorsal, unpaired outgrowth of the anterior end of the hind-brain; and (5) the *myelencephalon* or *medulla oblongata*, making up the remainder of the hind-brain. The rest of the embryonic

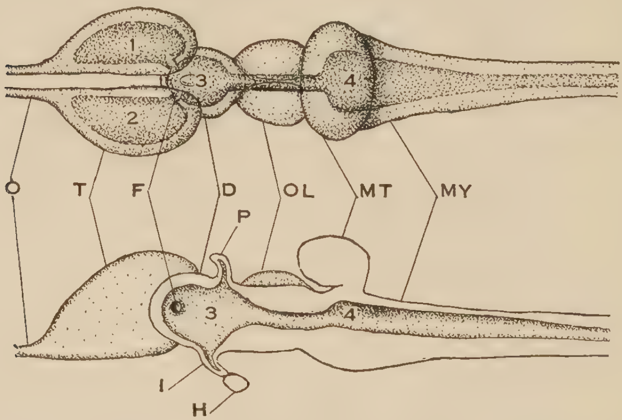


FIG. 99.—Diagram of vertebrate brain. A, dorsal view showing ventricles; B, median view of right half of brain. D, diencephalon; F, foramen of Monro; H, hypophysis attached to infundibulum, I; MT, metencephalon; MY, myelencephalon; O, olfactory tracts; OL, optic lobes of mesencephalon; P, pineal body; T, telencephalon; 1–4, ventricles.

neural tube forms the spinal cord. The brain is enclosed in the *cranium* of the skull, while the spinal cord lies in the cavity formed by the neural arches of the vertebrae.

Ventricles.—The cavity of the neural tube persists in the adult brain in the form of ventricles, of which the first and the second lie in the cerebral hemispheres and are connected by narrow passages, the *foramina of Monro*, with the third ventricle which is the cavity of the diencephalon. In higher vertebrates the cavity of the mesencephalon is a narrow tube, the *iter* or *aqueduct of Sylvius*, but in lower vertebrates it is expanded dorsally into the *epicœl* in the dorsal part of the optic lobes.

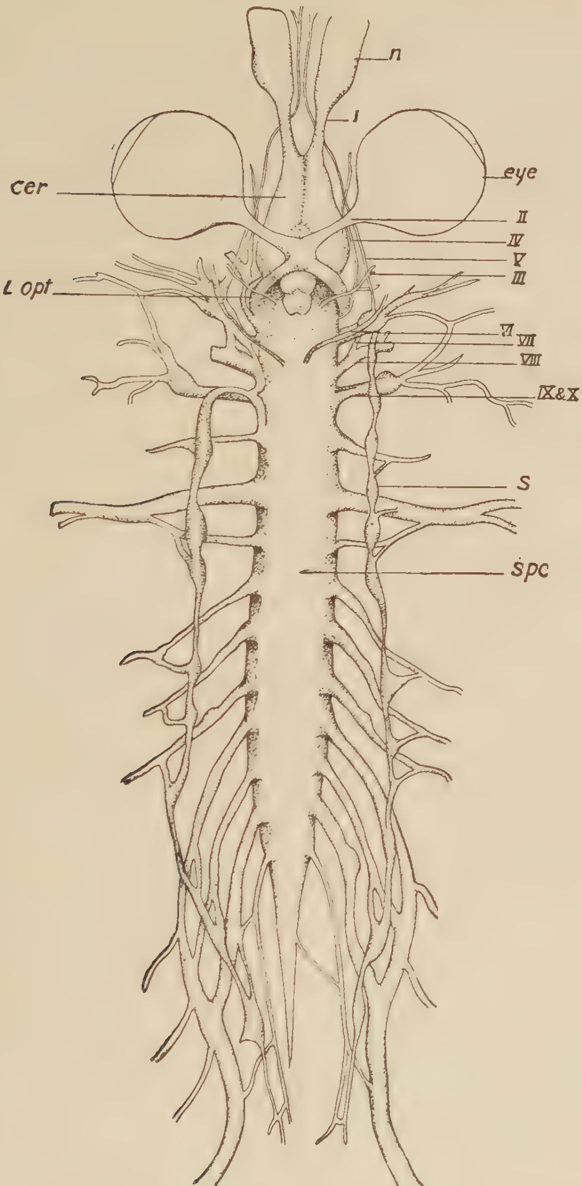


FIG. 100.—Nervous system of frog showing cranial and spinal nerves and sympathetic system, ventral view. *I–X*, cranial nerves; *cer*, cerebrum; *l.opt*, optic lobe; *n*, nasal sac; *s*, sympathetic system; *spc*, spinal cord. (*From Shull, LaRue and Ruthven, Animal Biology, after Wiedersheim.*)

The iter leads to the fourth ventricle in the medulla, from which the channel continues through the spinal cord as the spinal canal.

Pituitary and Pineal Body.—An evagination in the floor of the diencephalon, known as the *infundibulum,* unites with the *hypophysis,* a dorsal outgrowth pinched off from the embryonic oral cavity, to form the pituitary body. An evagination from the roof of the diencephalon forms the pineal body.

Cranial Nerves.—The nerves connecting the brain with different parts of the head and adjacent regions are the cranial nerves. Some of these nerves are purely sensory in function, some motor, and others both motor and sensory. There are 12 pairs designated both by name and Roman numbers as follows:

I. *Olfactory nerve,* purely sensory in function and extending from the *olfactory epithelium* of the nose to the cerebrum.

II. *Optic nerve,* sensory in function, having its origin in the *retina* of the eye, from which it extends across the ventral surface of the diencephalon to the optic lobes. There is a crossing of the fibers of the optic nerve at the *optic chiasma,* those from the left eye going in part to the right side of the brain, and vice versa.

III. *Oculomotor nerve,* a motor nerve arising from the ventral surface of the midbrain and passing to four of the extrinsic eye muscles: the *superior, inferior,* and *internal recti,* and the *inferior oblique* muscles.

IV. *Trochlear nerve,* also motor, passes from the dorsal surface of the hinder margin of the midbrain to the *superior oblique* eye muscle.

V. *Trigeminal nerve,* a large nerve arising from the antero-lateral angle of the medulla and dividing, in the higher vertebrates, into three main trunks: the *ophthalmic,* the *maxillary,* and the *mandibular.* The first two are sensory in function and supply the skin in the region of the eye, the roof of the mouth, the teeth of the upper jaw, etc., while the mandibular branch contains both motor and sensory fibers to the jaw muscles, tongue, teeth of the upper jaw, and adjacent parts. Near the point where it leaves the brain the trigeminal nerve has a *semilunar* (Gasserian) ganglion.

VI. *Abducens nerve,* a motor nerve coming from the ventral surface of the medulla and innervating the *external rectus* muscle of the eye.

VII. *Facial nerve,* arising by several roots from the medulla posterior to the fifth nerve. In the lower vertebrates it has

two ganglia, the *geniculate* and the *lateralis*, but the latter in higher forms is united with the geniculate or with the semilunar of the fifth, or it may be absent. The facial nerve is composed of both motor and sensory fibers, supplying various parts of the outer surface of the head, mouth, tongue, and glands.

VIII. *Auditory nerve*, purely sensory, extends from the sensory epithelium of the *inner ear* to the medulla. Near its junction with the brain is a large ganglion, from which a *vestibular* branch passes to the utriculus and a *cochlear* branch to the cochlea, the two main divisions of the inner ear.

IX. *Glossopharyngeal nerve*, a mixed nerve containing both motor and sensory fibers. It has a *petrosal* ganglion and is distributed principally to the pharynx and the tongue. Like the remaining cranial nerves, it has its origin in the medulla.

X. *Vagus nerve*, also a mixed nerve and in higher forms distributed to the œsophagus, stomach, heart, and other viscera. The *jugular* ganglion is found near its origin.

XI. *Spinal accessory nerve*, a motor nerve supplying the muscles of the pectoral region.

XII. *Hypoglossal nerve*, a motor nerve supplying the muscles of the neck and tongue.

The eleventh and twelfth are not present as cranial nerves in fishes and amphibia.

Long after the twelve cranial nerves were described, another pair was discovered leaving the brain at its anterior end. This nerve, which should really be the first in the series, is known as the *Nervus terminalis*. It has been found in all vertebrates, but is easily overlooked because of its inconspicuousness, which accounts for its remaining undiscovered until a relatively recent time. It is distributed in the upper part of the *nasal epithelium* in man, but nothing of a definite character is known of its function.

Spinal Nerves.—The spinal cord is connected with peripheral regions of the body by the spinal nerves. They are paired and extend laterally from the cord through openings between the vertebrae. Each spinal nerve has two roots, a *dorsal* root carrying a ganglion and a *ventral* root without ganglion. The *ganglion* is made up largely of nerve cell bodies whose axons pass into the cord and whose dendrons enter from the periphery, the whole forming the dorsal root. The ventral root is composed of axons whose cell bodies lie in the cord. The dorsal root, except in a few of the lower vertebrates,

is purely sensory in function, while the ventral root is motor. The two roots come together a short distance from the cord to form a *spinal nerve*, which then divides into three branches, each containing motor and sensory fibers. The branches are (1) a *ramus dorsalis*, passing to the skin and the muscles of the dorsal region; (2) the *ramus ventralis*, to the muscles of the ventral part of the body wall and the appendages; (3) the *ramus*

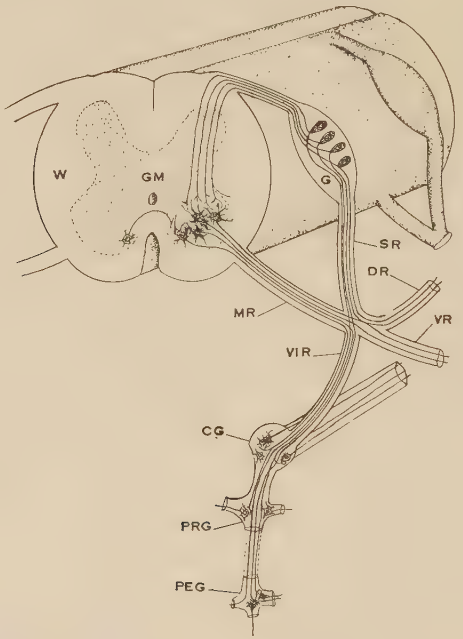


Fig. 101.—Diagram showing relation of spinal nerve to cord and sympathetic nervous system. CG, chain ganglion of sympathetic system; DR, dorsal ramus of spinal nerve; G, spinal ganglion, containing cell bodies of sensory neurons; GM, gray matter of cord; MR, motor spinal root, whose cell bodies lie in the ventral horn of gray matter of cord; PEG, peripheral sympathetic ganglion; PRG, prevertebral sympathetic ganglion; SR, sensory spinal root; VIR, visceral ramus of spinal nerve; VR, ventral ramus of spinal nerve; W, white matter of cord.

visceralis, extending ventrally into the body cavity, where it connects with the *sympathetic* nervous system.

The *functional significance* of the two roots of the spinal nerves can be demonstrated by experiments. Thus, if a dog be anesthetized and the *ventral roots* of the spinal nerves supplying the forelimb cut, the animal loses control of the muscles supplied by these nerves, although sensitivity to pain in the skin of the

limb remains. If the *dorsal roots* be cut instead of the ventral, sensation in the limb is lost, but power to move the muscles remains. If both dorsal and ventral roots be cut, stimulation by an electric current of the distal end of the ventral root causes contractions of the muscles of the limb, while stimulation of the central end of the cut ventral root produces no effect. Neither is any effect produced by stimulating the distal end of the cut dorsal root; but stimulation of the central end of the same root causes symptoms of pain. The dorsal root is therefore sensory in function, and the ventral root motor.

Sympathetic Nervous System.—This consists of three parts: (1) a *chain of ganglia* lying against the dorsal wall of the body cavity on either side of the vertebral column and connected with each other by longitudinal cords, (2) a number of *prevertebral ganglia*, such as the *cardiac, pelvic, solar plexus*, etc., lying ventral to the chain ganglia with which they are connected by nerves; (3) *peripheral ganglia*, located in the viscera, often at some distance from the centers. In its development the sympathetic system is derived from the neural tube *via* the ramus visceralis along which nerve cells migrate ventrally. A connection between the central and sympathetic nervous system is retained throughout life by the visceral branches of the spinal nerves in the region of the spinal cord, and by visceral branches of cranial nerves (V to XII) in more anterior regions. The function of the sympathetic nervous system is to control the action of *smooth muscles* of the alimentary canal and blood vessels, the *secretory activity* of certain glands, and the action of the *heart* and the *viscera* generally. Fibers arising from sympathetic nerve cells are *non-medullated.*

Sense Organs.—The structures adapted to receive *stimuli* from without, and transform them into *nervous impulses*, which then pass along sensory nerves to the central nervous systems where, as a result, *sensations* of various kinds are produced are the sense organs. The classification of sense organs in animals is based on the knowledge of sense organs in man, since knowledge of sense organs in other animals is gained only by analogy with human experiences. Accordingly, sense organs are grouped under the following heads: (1) *tactile* organs, which include, beside *touch*, receptors for *pain*, *temperature*, and *muscle-sense* stimuli; (2) organs of *taste;* (3) organs of *smell;* (4) organs of *sight;* (5) organs of *hearing;* and (6) organs of *equilibration.*

Tactile Organs.—The integument of animals is usually *tactile* over its entire surface, but the degree of sensitivity may vary in different regions. Thus, in man the tip of the tongue or the ends of the fingers are far more sensitive to touch than the skin of the back. The *tactile bristles* or *hairs* of arthropods are examples of special tactile end organs commonly found in invertebrates. The tactile hair is not a nerve ending but a development of the epidermis in contact with a nerve ending at its base, so that any movement of the hair is communicated to the nerves. In vertebrates the *tactile corpuscle* is a capsule-like structure, enclosing a nerve ending, and is found embedded in the skin, alimentary canal, muscles, etc. Thus, the *corpuscle of Pacini*, ovoid, laminated bodies with a nervous core, are found in numbers near joints and ligaments, and are thought to be end organs for tactile sensations caused by the movement of one bone upon another, such as accompanies any voluntary muscular movement. In the muscles themselves are found *neuro-muscular spindles* which during muscular movement are compressed, and thus serve as end organs of what is called the *muscular sense*, that is, the sensation associated with muscular movement. Physiologically, in man the surface of the skin is made up of a great number of very small areas, each of which is specially related to one or more of the sensations of *touch*, *heat*, *cold*, and *pain*. Areas concerned in one sensation are everywhere mingled with areas concerned in others. It has been ascertained that there exist in the skin of the trunk and limbs 30,000 *warm spots* which always react to stimulation with a sensation of warmth, 25,000 *cold spots*, 500,000 *touch spots*; while *pain spots* seem to be present

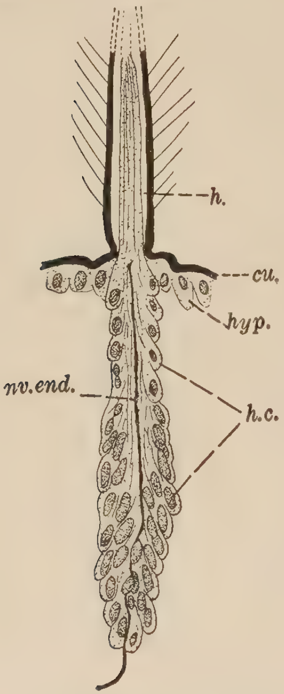


FIG. 102.—Tactile end-organ of a nerve fiber in the tactile hair of a shrimp, *Palæmonetes*. *cu.*, cuticle; *hyp.*, hypodermis, which is invaginated at (*h.c.*) into the hair cells. *h.*, outer structure of the hair; *nv.end.*, nerve ending in the lower part of the hair. (*From Dahlgren and Kepner, Principles of Animal Histology, copyright, The Macmillan Company. By permission.*)

everywhere. It is natural to expect that each of these four kinds of areas would be supplied by *different* receptors, but as yet it has been possible to interpret the function of a nerve ending from its structure to only a limited extent. However, there is reason to believe that the end organs of touch in the skin are circular arrangements of nerve fibers found about the hair follicles; and, where hair follicles are lacking, tactile corpuscles of various sorts occur. The skin also contains many naked endings of sensory nerves, the specific function of which is unknown.

Organs of Taste.—A sense of *taste* is probably present in all animals, but since the end organs of both taste and smell are activated by *chemical* stimuli it is often difficult in lower animals to differentiate between the two. Thus, if a piece of crushed clam be placed near the mouth of the burrow of *Nereis virens*, a marine annelid, the animal responds by thrusting its anterior end out of the burrow toward the food, which it seizes and pulls back into its burrow. The animal evidently is stimulated by the meat juices, but whether by smell or by taste is difficult to decide. In vertebrates the end organs of taste are known as *taste buds*. Each consists of a number of *taste* cells provided with bristles at their outer ends and a number of *supporting* cells, the whole forming a spherical body buried in the surrounding tissue but opening by a pore on the surface at one point. The outer ends of the taste cells converge at the pore. In fishes, taste buds occur in the walls of the *pharynx*, on the *gills*, on the outside of the body, and in some *(catfish)* on the *tail* and the *barbules*. In higher verebrates they are restricted to the oral cavity, where they are found on the *tongue, soft palate,* and *epiglottis*. The base of each taste cell is in contact with a nerve ending from which the stimulus is conveyed to the brain. In mammals the nerves involved in the sense of taste are a branch (*chorda tympani*) of the seventh cranial nerve and the *lingual* branch of the ninth.

FIG. 103.—Section of a taste-bud, diagrammatic. Four taste cells are shown with their outer ends converging toward the pit opening on the surface above. The inner ends of the cells are in contact with nerves entering the base of the bud. The pale cells within the bud are supporting cells.

Organs of Smell or Olfactory Organs.—These organs are stimulated by chemical stimuli, but the amount of the stimulating agent required is very much less than in the sense of taste. Smell is "taste at a distance" (Kant). It has been pretty well established that organs of smell exist in *insects* and probably in other invertebrates such as *snails.* The antennae of insects and other parts of the body bear *olfactory pits* in which the sensory cells lie. In vertebrates except *Cyclostomata*, the olfactory organs consist of paired sensory areas which in fishes lie at the bottom of *ectodermal pits* opening to the outside by nostrils but having no connection with the pharynx. In all air-breathing vertebrates these pits continue backward as *nasal passages* opening into the pharynx by *internal nares.* The sensory epithelium lining the passages consists of *olfactory* cells and *supporting* cells, the former bearing bristles at their outer ends while their inner ends are continued backward as *nerve fibers* forming the olfactory nerve. Since the olfactory cells arise and remain in the ectoderm, the olfactory epithelium is said to be the most primitive nervous epithelium in the body.

Fig. 104.—Section of human olfactory epithelium, diagrammatic. The slender outer ends of the olfactory cells are ciliated. The process leaving the base of each olfactory cell is a nerve fiber.

Organs of Sight.—Sensitivity to light is a characteristic of protoplasm exhibited in its simplest form by organisms being attracted or repelled by light. *Phototaxis*, as this reaction is called, occurs even in forms that have no special organs for receiving light stimuli, such as Protozoa, Hydra, and many worms. The visual organ in the lower forms is often merely an organ for detecting different *degrees* of light. Thus, in *Planaria gonocephala* the eye consists of a cup-shaped structure lined with pigment into which project the processes of twenty or more *visual* cells, each process being somewhat thickened at its distal end to form a *rhabdome.* Distally, the visual cells are continued as processes that form the *optic* nerve, connected with the central nervous system. Light passes through the transparent epithelium covering the eye and through the cell bodies of the visual cells until it strikes the rhabdomes, the *percipient* elements of the eye. The inpulse travels back through the visual cells to the brain.

Compound Eye. In insects and other arthropods this organ consists of an outer transparent *cornea* divided into thousands of hexagonal *facets*, which are the outer bases of thin truncated cones, or *ommatidia*. The inner smaller ends of the latter rest upon a hemispherical membrane. Each ommatidium is made up of a *lens* lying beneath the cornea and supported by cells, and usually seven *retinal* cells. The retinal cells form the inner end of the ommatidium and are elongated in shape, the inner edge of each bearing a *rhabdome* composed of a row of small plates or rods. Since the rods project at right angles to the axis of the cells, they intercept light

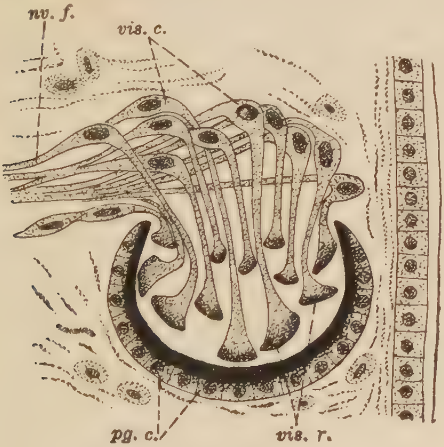


FIG. 105.

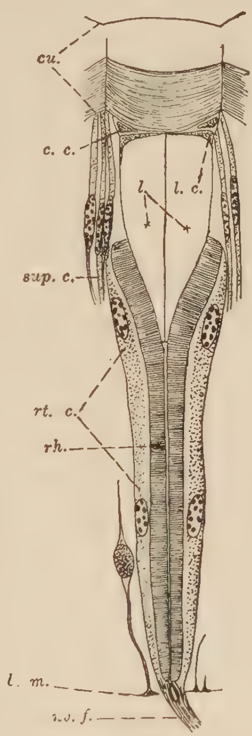


FIG. 106.

FIG. 105.—Axial section of the eye of *Planaria gonocephala*. *vis. c.*, visual cells; *vis. r.*, visual rods or rhabdomes; *nv. f.*, centripetal fibers of visual cells; *pg. c.*, pigment cells. (*From Dahlgren and Kepner, Principles of Animal Histology, copyright, The Macmillan Co., after R. Hesse. By permission.*)

FIG. 106.—Longitudinal section of a single ommatidium of a roach, *Periplaneta orientalis*. *b. m.*, basement membrane; *cu.*, cuticle divided into corneal areas; *rt. c.*, retinal cells; *rh.*, rhabdome or cell organ of light perception; *l.*, lens; *l.c.*, lens cells; *c. c.*, corneal cells; *sup. c.*, supporting cells; *nv. f.*, nerve fiber. (*From Dahlgren and Kepner, Principles of Animal Histology, copyright, The Macmillan Co., after R. Hesse. By permission.*)

entering the ommatidium through the cornea. The lower ends of the retinal cells are prolonged into nerve fibers which form an optic nerve passing inward to the central nervous system. Rays from a given point will pass into a certain ommatidium; rays

from a different point into another ommatidium; while rays striking obliquely are stopped by opaque sheaths of *pigment* between the ommatidia. Under certain conditions the pigment may withdraw, and then light from a single point effects a large number of ommatidia. Such an eye would seem to be especially adapted for recording moving objects, since a change in the position of an object reflecting light effects, in turn, a number of ommatidia. This may be demonstrated by a simple experiment. If the hand is moved slowly toward a grasshopper, the grasshopper shows no tendency to escape until it is almost touched; on the other hand, if the movement of the hand is rapid, the grasshopper leaps long before the hand is near it.

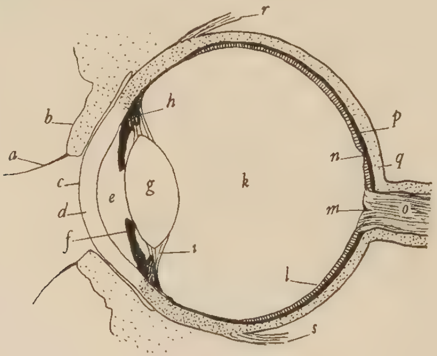


FIG. 107.—Diagram of a vertical section of human eye and eyelids. *a*, eyelash; *b*, lid; *c*, conjunctiva, a thin membrane continuous with the lining of the eyelid; *d*, cornea; *e*, anterior chamber filled with aqueous humor; *f*, iris; *g*, lens; *h*, muscles to ligament suspending lens; *i*, suspensory ligament of lens; *k*, posterior chamber filled with vitreous humor; *l*, retina; *m*, blind spot; *n*, fovea centralis; *o*, optic nerve; *p*. sclera; *q*, choroid coat; *r*, superior rectus muscle of eyeball; *s*, inferior rectus muscle.

Vertebrate Eye.—Not only is the vertebrate eye adapted for perceiving differences in *intensity* of light, but is also capable of forming *images.* In man, the shape of the eye is roughly that of a sphere whose curvature in the region of the transparent part in front is somewhat greater than elsewhere. The outer covering is made up of the transparent *cornea* in front, and the tough and opaque *sclerotic* coat, or *sclera,* forming the remainder, the white of the eye. Beneath the sclera lies the pigmented and vascular *choroid;* beneath which, in turn, is the *retina.* Neither of these latter layers extend in front beyond the line of junction of the cornea and sclera. The *lens* is a doubly convex transparent disc enclosed in a capsule, and held in place by a *suspensory ligament*

which attaches it to the wall of the eye along the line of the forward edge of the choroid coat. The lens divides the eye into an anterior region filled with a liquid, the *aqueous humor*, and a posterior region containing a jelly-like *vitreous humor*. These two fluids keep the eye distended. The anterior region of the eye is further divided into an *anterior* and *posterior* chamber by the *iris*, a pigmented muscular curtain with an opening, the *pupil*, in its center. The iris lies just in front of the lens and is attached at its outer edge to the *ciliary process*, a circle of

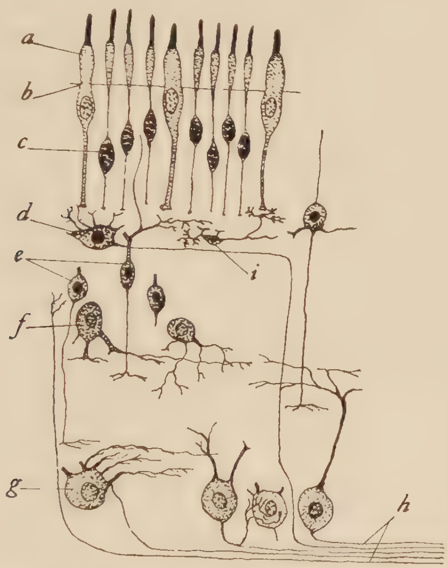


FIG. 108.—Diagram of human retina. *a*, cone cell; *b*, membrana limitans externa; *c*, rod cell; *d*, stellate ganglion cell; *e*, bipolar cell; *f*, amkrine ganglion cell (axons have not been found); *g*, multipolar ganglion cell; *h*, nerve fiber layer, at inner surface of retina; *i*, subepithelial ganglion cell. (*After Stöhr.*)

smooth musculature interposed between the corneosclerotic juncture and the choroid. The amount of light entering the eye is controlled by altering the size of the pupil.

Retina.—Beginning at the outside, the retina is made up of *rods* and *cones*, cells whose ends point outward toward the choroid. The processes from the rods and cones connect internally by a number of intermediate neurons with large *ganglion cells* lying at the inner surface of the retina. Axons leave the ganglion cells from all over the inner surface of the retina and come together at the *blind spot* to form the optic nerve going to the brain. The blind

spot is not in the direct line of vision, being toward the nasal side of the center of the eye. At the point lying in the optical center of the eye, rods are absent, and the other retinal layers greatly reduced. The slight depression at this spot is known as the *fovea centralis* and it is the point of most acute vision.

Light Perception.—The rods and cones are the *percipent* elements. Light enters the eye through the cornea, which converges the rays, and passes through the lens where the rays are further converged and brought to a focus upon the retina. Before reaching the rods and cones it is necessary for the light to traverse the various layers of the retina lying between them and the inner surface. The rods and cones having been stimulated by the light, the impulse set up passes in the reverse direction from the rods and cones to the fibers forming the optic nerve, which conveys the stimulus to the brain. There is evidence to show that the cones are concerned in both *chromatic* and *achromatic* vision, while the rods are concerned in *achromatic* vision alone. Cones are entirely lacking in the eyes of some lizards.

Accommodation.—The human eye possesses great range of vision—a mountain miles away and a printed page at a distance of as many inches can be seen with equal clearness. The power of *accommodation* for objects at varying distances is due to the fact that the focal length of the lens can be changed. In the eye of some molluscs, like the *squid*, and in the eye of all fishes, accommodation is brought about by altering the distance between the lens and the retina, as in a camera (where the sensitive plate or film takes the place of the retina). In *mammals*, however, the same end is accomplished by altering the *curvature* of the lens, and therefore its focal length. According to the generally accepted explanation, this adjustment is brought about by the contraction of the *ciliary muscles*. When the eye is relaxed, unaccommodated. the suspensory ligament and the capsule containing the lens are taut, making the front surface of the lens relatively flat, so that light from a distant object is focussed without any effort. For nearer objects the lens is made more *convex* by the contraction of the ciliary muscle pulling forward the region of attachment of the suspensory ligament to the eyeball, thus easing the tension on the ligament. As a result, the lens thickens and increases in *convexity* until checked by the tension of the capsule.

Eye Muscles.—By means of six *extrinsic* eye muscles the mammalian eyeball can be rotated in all directions through

a considerable arc. The *internal* and *external rectus* muscles move the eye from side to side; the *superior* and *inferior rectus* muscles move it up and down; and the *superior* and *inferior oblique* muscles make possible movements obliquely. In Amphibia the *retractor bulbi* is developed from the external rectus and serves to pull the eyeball into the pocket.

Organs of Hearing and Equilibration. —Organs of hearing are not well developed among invertebrates. In insects the *tympanal organ* of the *Orthoptera*, grasshopper, roach, etc., is undoubtedly concerned in hearing. It is a paired organ consisting of a thin *chitinous membrane* stretched like a drumhead across a supporting frame, beneath which is a *tracheal vesicle* containing a nerve which ends in a *crista acustica*. Sound waves impinging upon the membrane cause it to vibrate and thus stimulate the nerve ending.

Organs of the Equilibration.—In both invertebrates and vertebrates organs of equilibrations are found. In *Crustacea*, crayfish, lobster, shrimp, etc. the organ is known as a *statocyst* or *lithocyst*, a sac lined with chitin and located in the basal segment of each antennule. Projecting from the wall of the sac into its cavity is a number of *sensory hairs*, among which are found a few grains of sand called *statoliths*. Changes in position of the body displace the statoliths among the hairs, the differential stimulation of which informs the animal of its position in space. This interpretation of the function of the statocyst is borne out by the fact that when the animal molts—a process in which the entire chitinous covering of the body, including the lining of the statocyst and the contained statoliths, is lost—the animal for a time lacks full power of orientation. The same is true of animals who have lost their statoliths in other ways. The most convincing evidence regarding the function of the organ is based upon an experiment first performed by Kreidl. He placed shrimps, newly molted and therefore without statoliths, in water containing iron filings. In the absence of sand grains to replace the discarded statoliths, the experimental animals made use of the iron filings which they placed in the statocyst. When an electromagnet of sufficient strength was brought near, the shrimp oriented itself with reference to the *resultant* of the lines of force of the magnet and gravity as it would

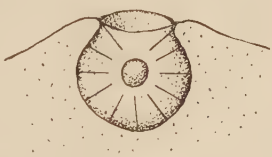


FIG. 109.—Diagram of a statocyst.

to gravity alone. From which the conclusion is drawn that contact with certain hairs in the statocyst gives one response in space, while stimulation of other hairs gives a different response.

Inner Ear.—The organ of both *hearing* and *equilibration* in the vertebrates is the inner ear. Above fishes there is also a *middle ear*, to which in mammals there is added a third region, the *external ear*. The inner ear arises as an invagination of the ectoderm in the region of the embryonic hind-brain to form the *otic sac* which later becomes embedded in the cartilage or bone of the skull, as

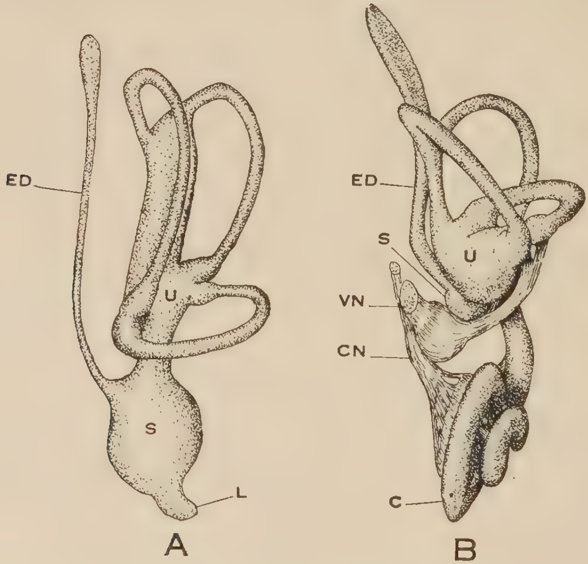


FIG. 110.—A, diagram of membranous labyrinth of ower lvertebrate. B, membranous labyrinth of human embryo, 30 cm. in length. C, cochlea (scala media); CN, cochlear nerve; ED, endolymphatic duct; L, lagena; S, sacculus; U, utriculus; VN, vestibular nerve. (B, *After Streeter*.)

the case may be. Two regions develop in the otic sac: (1) the *utriculus*, bearing three *semicircular canals*, and (2) the *sacculus*, which in fishes is a rounded sac with a short appendage, the *lagena* Fig. 110 (*A*). In higher vertebrates the saccular region becomes progressively larger until in mammals it has the shape of a spiral tube known as the *scala media* Fig. 110 (*B*). The utriculus with its canals has to do with equilibration, while the sacculus, the lagena, and its derivatives are concerned with hearing. Fishes are practically deaf as far as discrimination of pitch is concerned, which is correlated with the slight development of the

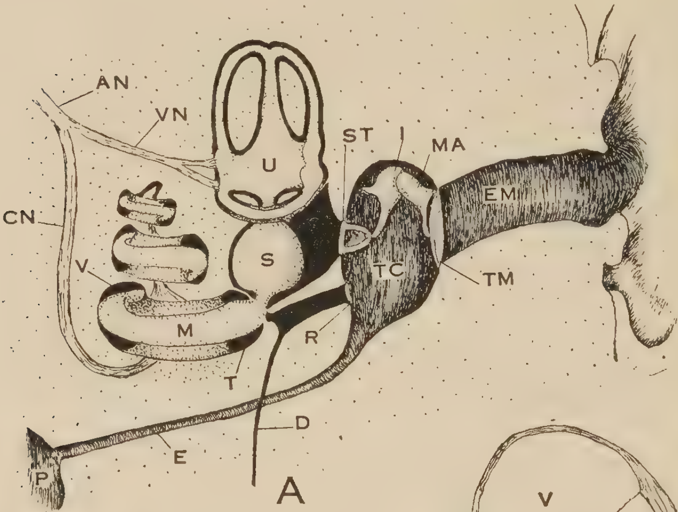
lagena.[1] The two general regions are connected by the *sacculo-utricular canal*. The *endolymphatic duct* is a slender tube, arising from the sacculoutricular canal and extending, in the dogfish to the surface of the head, where it opens to the outside. In other forms it ends blindly in the skull.

These various parts of the inner ear constitute what is known as the *membranous labyrinth*. It is filled throughout with a fluid, the *endolymph*, which contains *otoliths* composed of microscopic crystals of calcium carbonate. Areas of sensory epithelia consisting of large cells with long hairs, *crystae acusticae*, are located in the enlarged ends of each semicircular canal, while other areas of cells with shorter hairs, *maculae acusticae*, occur in the utriculus, sacculus, and scala media. In *mammals* the skeletal labyrinth consists of a casing of bone closely following the various parts of the membranous labyrinth. The part enclosing the scala media is the *cochlea*. The two labyrinths are incompletely separated by a space filled with *perilymphatic fluid*. In the cochlea the perilymphatic space of each turn of the bony labyrinth is divided by the scala media into a *scala vestibuli* above and a *scala tympani* below, the two being continuous at the apex of the cochlea. The skeletal labyrinth is pierced by two openings toward the middle ear: (1) the *fenestra rotunda*, located at the base of the cochlea, where the scala tympani terminates, and closed by a membrane; (2) the *fenestra ovalis*, in the region of the sacculus (*vestibulum*), closed by a bone of the middle ear, the *stapes*. (Fig. 111.)

Middle Ear or Tympanum.—Lying in front of and below the inner ear is a chamber, the middle ear. Internally, it is connected with the pharynx by a slender duct, the *Eustachian tube*, and externally it is closed by the tympanic membrane. From the latter a chain of small bones, *ear ossicles*, extend across the cavity to the fenestra ovalis. In amphibia, reptiles, and birds only two ear bones are present, the *columella* and *stapes*. The former extends from the tympanic membrane to the stapes which is fitted at its inner end into the fenestra ovalis. In mammals the columella is replaced by two bones, the *malleus* next to the tympanic membrane, and the *incus* extending from the malleus to the stapes.

[1] Recent experiments (Manning, 1924) show that goldfish respond to vibrations under water. By removing parts of the inner ear it was determined that the utriculus is sensitive to vibration rates of 43 to 688, and the sacculolagena to the rates of 688 to 2752 per second.

External Ear.—In mammals the external ear consists of the *conch,* the funnel-shaped external structure whose function is to collect sound waves and direct them into the *external auditory meatus* leading to the tympanic membrane.



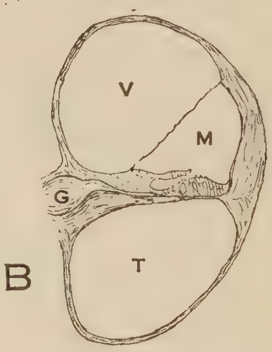


FIG. 111.—A, diagram of mammalian ear; B, cross-section of one of coils of cochlea. AN, auditory nerve; CN, cochlear nerve; D, perilymphatic duct; E, Eustachian tube; EM, external meatus; G, spiral ganglion; I, incus; M, scala media; MA, malleus; P, pharynx; R, foramen rotunda; S, sacculus; ST, stapes; T, scala tympani; TC, tympanic cavity; TM, tympanic membrane; U, utriculus; V, scala vestibuli; VN, vestibular nerve. (*Modified from Kingsley, Comparative Anatomy of Vertebrates, P. Blakiston's Son & Co. By permission.*)

Equilibration.—The inner ear serves as an organ of equilibration by recording changes in position of the body. Every movement of the head causes the endolymph and the contained otoliths to stimulate the cristae acusticae in the semicircular canals from which impulses are carried to the brain by the *vestibular* branch of the eighth cranial nerve. The canals lie in planes at right angles to each other, so that movement in any direction is bound to effect one of them. The action of the fluid on the hairs can be illustrated by a simple experiment. If a glass of water be given a sudden rotary twist, the glass moves,

but the water tends to lag behind, so that if the glass had contained fine hairs extending from its sides into the water, these hairs would have been bent or otherwise disturbed by the water. In the same way, when the head moves, the endolymph in the canal lying in the plane of motion tends to remain stationary, while the sensitive hairs are dragged through it and stimulated. Thus, means are afforded for recognizing the direction and the amounts of the components of any motion. At the same time, sensory hairs in other parts of the utriculus and sacculus are also stimulated by the dispacement of otoliths among them.

Auditory Function.—Presumably, the sensory cells of the *organ of Corti*, which lies in the floor of the scala media perform the auditory function, Fig. 111 (*B*). Sound vibrations are transmitted from the tympanic membrane across the middle ear by the ossicles to the fenestra ovalis, where they are taken up by the perilymph. Vibrations thus set up in the perilymph pass up the scala vestibuli to the summit of the cochlea, and then down the scala tympani to the fenestra rotunda whose membrane moves in and out with the vibrations. In passing the scala media the vibrations in the perilymph are transmitted through the walls of the membranous labyrinth, eventually stimulating the hair cells of the organ of Corti. The auditory impulses are conveyed to the brain by the *cochlear* branch of the eighth nerve. There is some question as to the function of the organ of Corti, since none is present in birds, and birds undoubtedly have a sense of hearing. (Kingsley).

The Functional Significance of the Nervous System.—The first appearance of the nervous system of the lower invertebrates, as has already been pointed out, does not involve the origin of a new functional activity, but merely a specialization of the functions of excitation and transmission which are common property of all forms of protoplasm. Protozoa are sensitive to the same stimuli which effect the higher forms, yet they lack a nervous system. The importance of a nervous system becomes more and more pronounced with the increase in size and complexity of the individual, because the need of a rapid excitation and transmission system becomes greater and greater. The significance of the ever-growing complexity of the central nervous system particularly, as the animal scale is ascended, consists in its function as a mechanism for *integration*. A large animal without proper nervous control would be merely a mass of protoplasm incapable of finely coordinated activities. The nervous system

with its ramifications in all parts of the body connecting with so-called centers in the brain and spinal cord provides a means for properly coordinating functional activities which brings about an *integrative result*, so that the activities of the widely separated parts of the body, instead of functioning as uncoordinated independent units, function as *parts of a whole*.

With this chapter is concluded a general survey of the systems of animal organs—a bird's-eye view of the organ equipment by which organic functions are accomplished in animals. It has been mainly morphological in character, although the attempt has been made to consider function along with structure so far as possible. The two following chapters deal primarily with function as considered from the general standpoint of metabolism. For practical reasons metabolism is considered for the most part from the side of human physiology, because, after all, more is known about the metabolism of man than of any other animal.

CHAPTER XI

METABOLISM

The living state is characterized by continuous physical and chemical changes in the cells of the body, as a result of which, energy, largely in the form of heat, is evolved and carbon dioxide and other excretory products are generated. The amounts of these different items vary with the degree of activity of the body, but even when an organism is at rest or asleep there is a ceaseless expenditure of energy and a loss of matter. Metabolism is the sum total of these changes.

Loss of Energy.—An adult man who eats nothing and remains as inactive as possible expends energy in the form of heat to the extent of about 1,870 large *calories* in twenty-four hours. A large calorie is the amount of heat required to raise the temperature of 1,000 grams of water 1° C. If he takes food but remains otherwise inactive, he expends 10 per cent additional energy in eating and digesting it. If he indulges in a moderate amount of exercise the total energy lost in twenty-four hours is 2,500 calories. If he performs hard manual labor, his energy output ranges between 3,500 and 5,000 calories per day. The energy loss results from the production of *heat* involved in muscular action and in the functional activity of other organs.

Loss of Matter.—The daily loss of material in the average man is about 3,900 grams, of which 2,800 grams are in the form of *water*, 30 grams *inorganic salts*, and the remainder, *carbon dioxide* and *nitrogen* compounds. From the *lungs*, carbon dioxide and water are lost; from the *skin*, by perspiration, water, carbon dioxide, traces of salts, and urea; from the *kidneys*, water, salts, urea, uric acid, and other nitrogen-containing compounds; and, lastly, from the *rectum*, water, salts, and undigested remnants of food.

Food.—These losses in matter and energy are made up by taking, as food, substances containing the same *chemical elements* as those lost and of such a chemical *composition* as to be capable of replacing worn-out tissue substance. Food for animals must be

closely allied in chemical composition to animal tissues, that is, it must be *combustible* material capable of ready oxidation in the animal body. In this regard the requirements of animals differ markedly from those of *chlorophyll-bearing* plants, in that the latter can, with the aid of the sun's rays, form complex compounds from simple inorganic substances derived from the soil and air. The constituents of the food of animals correspond closely in composition to the chief constituents of protoplasm and, accordingly, may be classified as follows:

Organic constituents.

1. *Proteins*, nitrogen-containing substances, like myosin of meat, casein of milk, gluten of bread, or albumen of eggs.
2. *Fats* and *oils*, such as palmitin of butter, stearin of beef fat, olive oil, etc.
3. *Carbohydrates*, which include starches and sugars.

Inorganic Constituents.

1. *Water*.
2. *Inorganic salts*, such as chlorides, sulphates, phosphates, and carbonates of sodium, potassium, magnesium, calcium, etc.

Food constituents, except water, cane sugar, and sodium chloride, are not ordinarily used as separate articles of diet. Any single article of food, such as rice or meat, may contain all the food constituents, but since in meat the protein constituent predominates, it is ordinarily classified as protein food. Similarly, rice or potatoes would be considered as carbohydrates, and butter as fat.

Vitamines.—In addition to protein, carbohydrate, and fat, the body requires another class of organic substances, which are known as *vitamines*. A number of them have been identified, though not completely isolated in a pure state, so that their chemical formulas are not known with any degree of certainty. Nevertheless, their importance as essential constituents of diet has been established beyond all question, and must be taken into account in all studies of nutrition. Vitamines occur in milk, fruits, fresh vegetables, and meat, and in the outer layer of the kernels of grain.

If fowls are fed on *polished* rice (rice in which the reddish outside layer has been polished off) they develop in the course of a few days what is known as *polyneuritis*, a disease characterized by nervous degeneration and terminating fatally in a short time.

A tropical disease with somewhat similar symptoms, *beriberi*, is common among rice-eating people, and the cause is very likely the same in the two cases, since beriberi does not occur when *unpolished* rice is eaten. Similarly, *pellagra* seems to result from eating spoiled maize, that is, maize in which the vitamine-bearing component has been damaged or destroyed. *Scurvy* follows from too exclusive a diet of salted or preserved meats. Each of these diseases is due to the absence in the diet of a necessary substance called a vitamine.

While the actual chemical composition of none of the vitamines is known, it is perfectly clear from what has been said that they are indispensable constituents of food, and this must be borne in mind in the discussion in the following paragraphs, even though the exact rôle played by vitamines in metabolism is an unsolved problem.

Energy Value of Foods. Determination of the energy value of food is made by burning, *oxidizing*, them in a *calorimeter*, an apparatus by means of which the heat liberated may be accurately measured. Only *organic* food is involved in these tests, however, since the inorganic constituents of the diet are incapable of further oxidation, and are, therefore, not energy-producing. The organic substances, on the other hand, when taken into the body contain *potential* energy in a chemical form. The amount of this potential energy is proportional to the amount of energy expended in building up the compound from simple elements, just as a bent spring possesses energy in proportion to the amount of work expended in bending it. If the ends of the spring are released, it straightens out and its potential energy is converted into *kinetic* energy. In the same way, when an organic compound is oxidized its complex *molecular arrangement* is destroyed and it decomposes into simpler components, in the process of which energy is released. Thus, a *molecule* of carbohydrate possesses potential energy as long as the *atoms* of carbon, oxygen, and hydrogen maintain a certain *spatial* relation in the molecule. When this relation is disturbed, as, for example, by an oxidizing agent, the structure collapses, energy is liberated in the form of heat, and the carbon, hydrogen, and oxygen emerge from the reaction as carbon dioxide and water.

By means of the calorimeter it has been found that 1 gram of *fat* yields 9.3 calories, 1 gram of *carbohydrate* 4.1 calories, and 1 gram of *protein* 5.0 calories. Except for protein, the

values represent the actual energy value of these substances to the body. Protein, however, is not completely oxidized in the body and it has been found that for every gram of protein ⅓ gram of *urea* is produced and excreted. Urea is capable of further oxidation; and since ⅓ gram of it represents 0.735 calories, in order to obtain the real calorific value of 1 gram of protein, 0.735 must be subtracted from 5, leaving 4.265 calories.

Protein.—Since protein is the only food constituent containing nitrogen, it is necessary in order to replace the nitrogen lost in metabolism. By itself, protein is not a good food for man—a purely protein diet not only causes digestive disturbances but also increases the metabolism of the tissues and, consequently, the *excretion* of nitrogen in abnormally large amounts. From this it appears that the energy of protein is not readily available to the body, and it would seem that its principal rôle is that of a *tissue builder*, although a certain amount is used as *fuel* and an *excess* may even be stored as fat.

Fats and Carbohydrates.—In moderate amounts these constituents are immediately oxidized in the body to produce heat and muscular work. They are primarily *energy producers.* An excess of either may be stored in the body as fat.

Water.—As a *solvent* water is necessary in the body, and, as such, promotes chemical reactions. It is also of great importance in regulating the *body temperature.* When perspiration evaporates from the surface of the skin, the latter is cooled, because water absorbs heat in passing from the liquid to the gaseous state. The same thing happens, of course, in the vaporization of water from the surface of the lungs.

Inorganic Salts.—These are as essential as other foodstuffs. A dog fed on a salt-free diet will die in the course of a month. Salts, in general, are necessary to maintain the proper *concentration* and *hydrogen-ion* content of the tissues and body fluids, while some have a specific function in building up hard parts, like the *bones* and *teeth*, or in meeting the special needs of certain tissues, as, for example, the requirement of *iron* in the manufacture of *hemoglobin.* Salts are also necessary to maintain the proper degree of *irritability* in cells. In man, sodium chloride and a certain amount of iodine in the form of table salt is the only salt deliberately added to the food. *Carnivorous* animals get enough sodium chloride in their food and apparently experience no craving for it such as is exhibited by animals subsisting on

a partial or complete vegetable diet. It is well known that *herbivorous* animals travel long distances to obtain salt from *salt licks*, which are natural outcroppings of mineral salt.

Digestion.—The function of the digestion is to convert food into a form readily absorbed through the walls of the alimentary canal, and capable of utilization by the tissues. Since the inorganic constituents are already soluble and are absorbed without further change, digestion has to do primarily with the organic foodstuffs. Although organic foodstuffs differ in chemical composition, digestion in all cases is brought about by the same sort of chemical process, namely, *hydrolysis.* In hydrolysis, the large, complex molecules of protein, carbohydrate, or fat, as the case may be, first combine with water and then undergo a *splitting* into simpler products. Complete digestion is not always effected by a single hydrolytic cleavage, the number of cleavages depending upon the nature of the food. To illustrate hydrolysis, what happens in the case of cane sugar, a *disaccharide,* may be considered:

$$\underset{\text{cane sugar}}{C_{12}H_{22}O_{11}} + \underset{\text{water}}{H_2O} \rightarrow \underset{\text{dextrose}}{2C_6H_{12}O_6}.$$

A molecule of water combines with a molecule of cane sugar, which then splits into two molecules of a simple (hexose) sugar, *dextrose.*

Enzymes.—The agents that bring about hydrolytic cleavage in the body are the enzymes. Their essential and characteristic properties may be summarized as follows:

1. Enzymes are not found in the products of the reaction, so that a *minimum* quantity of an enzyme can effect an unlimited transformation.

2. They are *soluble* in water and glycerin, and are rendered inactive at temperatures near 100° C.

3. They can be *precipitated* from solution by alcohol or salts like ammonium or zinc suphate.

4. They are *specific* in their action, which means that any given enzyme acts only upon a certain class of foods.

5. They are *sensitive* to the physical and chemical condition of the medium, that is, to the hydrogen-ion content. An enzyme normally acting in an alkaline medium becomes inactive in the presence of an acid.

6. They are *reversible* in their action. Under proper conditions they cause the products of hydrolysis to recombine to form the original substance.

7. Enzymes are products of *living cells*, but when removed from the body are capable of bringing about their characteristic reactions in a test tube. Some promote *oxidation*, some *reduction*, but the majority bring about *hydrolysis*.[1]

Catalysis.—The properties of enzymes are similar to the properties of inorganic *catalysts*. Thus, a solution of *colloidal platinum*, produced by passing an electric current of 8 to 10 amperes at 30 to 40 volts through water between platinum electrodes, has the properties of an oxidizing enzyme. It decomposes H_2O_2 (hydrogen peroxide); is sensitive to the presence of alkali; is retarded by certain poisons like hydrocyanic acid and is influenced by temperature (Bredig).

Digestive Enzymes.—In man the digestive enzymes are classified as follows:

1. *Proteolytic* enzymes, acting on proteins.

a. *Pepsin* is secreted by the glands of the stomach and acts in an *acid* medium.

b. *Trypsin* is secreted in an inactive form as *trypsinogen* by the pancreas, and becomes converted into *active trypsin* on reaching the intestine *via* the pancreatic duct. It acts in an *alkaline* medium.

c. *Erepsin* is secreted by the glands of the small intestine and acts in an *alkaline* medium.

2. *Diastatic* enzymes, acting on proteins in an *alkaline* medium.

a. *Ptyalin* is a constituent of saliva, secreted principally by the parotid gland.

b. *Amylopsin* is a product of the pancreas, acting in the small intestine.

3. *Lipolytic* enzymes, acting on fat in an *alkaline* medium.

a. *Lipase* is a product of the pancreas, acting in the small intestine.

4. *Inverting* enzymes, produced in the small intestine and converting double sugars into single sugars. They act in an *alkaline* medium.

a. *Maltase* acts on malt sugar.

b. *Sucrase* acts on cane sugar.

c. *Lactase* acts on milk sugar.

[1] The main facts in this summary of the properties of enzymes are taken from Effront and Prescott.

5. *Coagulating* enzymes.

a. Rennin is produced in the stomach, coagulates milk, and acts in an acid or neutral medium.

Digestion of Proteins.—Proteins are first acted upon in the stomach by pepsin, which in the presence of free hydrochloric acid secreted by the stomach, breaks pepsin down successively into *albuminates*, *proteoses*, and *peptones*—compounds of increasing solubility and simplicity of composition. Gastric digestion is facilitated by movements of the stomach, which churn the food and thoroughly mix it with gastric juice. These movements consist of *rhythmic* muscular contractions beginning at the middle of the stomach and passing toward the pylorus. As soon as an excess of acid begins to accumulate in the stomach, the pyloric sphincter muscle relaxes and allows a portion of the contents, now reduced to the consistency of a thick liquid called *chyme*, to pass into the small intestine. The sphincter then contracts and closes the passage from the stomach until the acidity of the chyme has been neutralized by the alkaline medium of the intestine, when the sphincter again relaxes and allows another portion of the chyme to pass through. Apparently, acid of a certain concentration on the stomach side of the sphincter causes it to *relax* but on the intestinal side causes it to *contract*. In this way the passage of chyme from the stomach to the intestine is carefully and automatically regulated.

In the small intestine trypsin and erepsin take up the digestion of protein where the pepsin left off, converting the peptone into *polypeptids* and these in turn into *amino acids*. The latter are soluble compounds of the general formula $R.NH_2.COOH$.

During intestinal digestion the chyme is subjected to two movements: (1) *rhythmic segmentation*, consisting of ring-like contractions of the circular muscles about an inch apart, succeeded rapidly by new ones midway between the first, the result of which is a thorough churning of the contents; (2) *peristalsis*, a series of slow gentle waves of contraction traversing the length of the intestine, which keep the contents moving toward the large intestine.

Digestion of Fats.—In the small intestine, fats are broken down through the action of lipase into *glycerin* and *fatty acids*. *Bile*, from the liver, although lacking a digestive enzyme, plays an important part in fat digestion, since lipase acts more rapidly and effectively when bile is present than when it is absent. The digestion of beef fat, *tristearin*, may be illustrated as follows:

$$\underset{\textit{tristearin}}{C_3H_5(C_{17}H_{35}COO)} + \underset{\textit{water}}{3H_2O} \rightarrow \underset{\textit{glycerin}}{C_3H_5(OH)_3} + \underset{\textit{stearic acid}}{3C_{17}H_{35}COOH.}$$

Since this reaction takes place in an alkaline medium, the free acid is at once neutralized to form a *soap, sodium stearate,* as follows:

$$\underset{\textit{stearic acid}}{C_{17}H_{35}COOH} + \underset{\substack{\textit{sodium}\\\textit{hydroxide}}}{NaOH} \rightarrow \underset{\substack{\textit{sodium}\\\textit{stearate}}}{C_{17}H_{35}COONa} + \underset{\textit{water}}{H_2O.}$$

Or, both steps may perhaps be combined in a single reaction as follows:

$$\underset{\textit{tristearin}}{C_3H_5(C_{17}H_{35}COO)} + \underset{\substack{\textit{sodium}\\\textit{hydroxide}}}{3NaOH} \rightarrow \underset{\textit{glycerin}}{C_3H_5(OH)_3} + \underset{\textit{sodium stearate}}{3C_{17}H_{35}COONa.}$$

Glycerin and a salt of a fatty acid, or soap, constitute the final products of the digestion of fats.

Digestion of Carbohydrates.—*Ptyalin* is produced principally by the parotid gland and to a much less extent by the submaxillary and sublingual glands. The principal secretion of the latter two is *mucin,* whose function is to aid in mastication and to lubricate the food thoroughly for swallowing. Ptyalin, which is reduced in amount or absent in purely carnivorous animals, acts upon starchy food in an alkaline medium. It is very sensitive to the presence of acid, 0.003 per cent hydrochloric acid being sufficient to stop its action. Ptyalin gradually converts starch into *maltose.* It is a step-by-step reaction, intermediate products being formed which take on more and more the character of sugar as the reaction goes on, as follows:

$$\textit{Starch}\begin{array}{l}\nearrow \textit{maltose}\\ \searrow \textit{erythrodextrin}\begin{array}{l}\nearrow \textit{maltose}\\ \searrow \textit{achroödextrin}\begin{array}{l}\nearrow \textit{maltose}\\ \searrow \textit{dextrin}, \text{ etc.}\end{array}\end{array}\end{array}$$

The action of ptyalin begins, of course, in the mouth, but continues for some time in the stomach, despite the fact that the stomach glands secrete hydrochloric acid. This is due to the manner in which the food is deposited in the stomach in layers, the first layer forming against the wall and each later layer forming inside the preceding. The last food swallowed lies, therefore, in the center of the stomach and farthest from the walls. Since

it requires time for the contents of the stomach to become thoroughly mixed with gastric juice, ptyalin continues active in the stomach for some time, especially in food swallowed toward the end of the meal.

In the small intestine *amylopsin*, whose action is identical with that of ptyalin, continues the digestion of starch until all of it is converted into maltose. The latter, as well as other sugars like cane sugar or milk sugar, is then converted into single sugars of the general formula $C_6H_{12}O_6$ by the *inverting* enzymes of the intestine.

Bacterial Digestion.—The intestine of man as well as that of other animals normally contains large numbers of bacteria. In the small intestine they cause *fermentation* of carbohydrates, which results in the production of carbon dioxide, alcohol, and acetic acid. These substances are probably absorbed and used by the body, but they could be used equally well if absorbed as unfermented sugar. In the large intestine the same thing may take place, but usually bacterial action in this part of the digestive tract is confined to undigested fragments of *protein*, causing *putrefaction*. *Autointoxication* results from the absorption in the large intestine of *toxic* substances formed in the process of putrefaction.

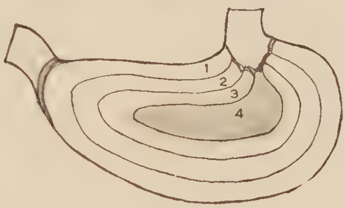


FIG. 112.—Diagram of stomach showing deposition of food in layers; the numerals refer to the order in which layers are formed.

Absorption. The products of digestion are, with the exceptions just noted, absorbed in the small intestine, which is especially adapted for the purpose. In man, the mucous lining of the small intestine throughout the greater part of its length is raised into permanent transverse folds, the *valvulae conniventes*. Both on the valvulae and between them the mucosa is in the form of closely packed finger-like processes called *villi*, an arrangement that is obviously for the purpose of increasing the absorbing surface. Between the bases of the villi the epithelium dips to form the *glands* that secrete the digestive enzymes of the intestine. Each villus is covered with *columnar epithelium* beneath which is an incomplete layer of *smooth muscle*, the whole being supported by a framework of connective tissue. In the center of the villus lie one or more *lymph* capillaries (*lacteals*) communicating with

larger vessels in the submucosa, which, in turn, lead to larger ones that pass out through the mesentery to join the main lymphatic system. Outside the lacteals, and beneath the mucosa, is a close network of blood vessels.

Absorption and Fate of Proteins.—The end products of protein digestion are *amino acids*, principally. These pass through the walls of the villus into the blood capillaries, whence they reach the general circulation. Traces of amino acids have been found

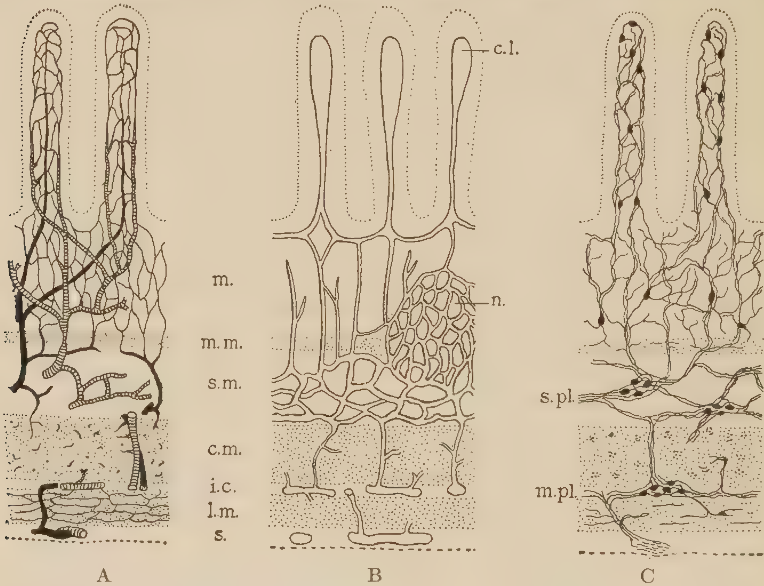


FIG. 113.—A, diagram of the blood vessels of the small intestine; the arteries appear as coarse black lines; and the capillaries as fine ones, and the veins are shaded (after Mall). B, diagram of the lymphatic vessels (after Mall). C, diagram of the nerves (after Cajal). The layers of the intestine are *m*, mucosa; *m.m.*, muscularis mucosa; *s.m.*, sub-mucosa; *c.m.*, circular muscle; *i.c.*, intermuscular connective tissue; *l.m.*, longitudinal muscle; *s*, serosa; *c.l.*, central lymphatic; *n.*, nodule; *s.p.*, submucous plexus; *m.pl.*, myenteric plexus. (*From Stöhr's Textbook of Histology, by Lewis. P. Blakiston's Son & Company. By permission.*)

in the blood of the portal vein, but the prevailing hypothesis is that the products of protein digestion are *synthesized* into blood proteins, *serum albumin*, or *globulin*, in passing through the walls of the intestine. The protein thus acquired is used where needed to repair tissue waste, any excess being utilized as *fuel protein* to produce energy. In the latter process a *nitrogen-containing* part separates from the protein molecule, leaving a *non-nitrogenous* residue of high energy value. This process of

deaminization, as it is called, is probably carried on by the tissues generally. The nitrogenous part split off in this way is waste composed of ammonia compounds, the chief of which is *ammonium carbonate*. These are discharged in the blood and in passing through the liver are converted into *urea* as follows:

$$\begin{array}{ccc} C{\diagup NH_3OH \atop = O \atop \diagdown NH_3OH} & \rightarrow C{\diagup NH_2 \atop = O \atop \diagdown NH_2} & + 2\,H_2O. \\ \textit{ammonium carbonate} & \textit{urea} & \textit{water} \end{array}$$

Urea is then removed from the circulation by the kidneys.

Absorption and Fate of Fats.—The end products of fat digestion are, as has been seen, *glycerin* and *soaps*. In passing through the walls of the villi these are converted into fats, since fat droplets can be observed in the columnar epithelium covering the villi. Such an observation can only be made on tissue taken from an animal during the process of absorption and prepared for microscopic examination. The *re-synthesized* fat passes first into the lacteals, then into the larger lymphatics, the thoracic lymph duct, and, finally, into the blood stream at the point where the thoracic duct joins the *subclavian vein* near the heart. Fats are primarily energy producers, since they

Fig. 114.

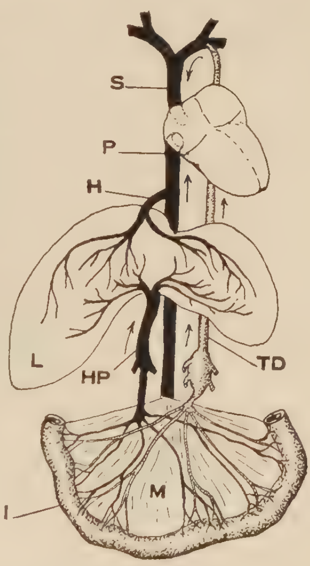


Fig. 115.

Fig. 114.—Intestinal epithelium of frog showing spherules of fat (in black) as they appear during absorption. (*After Krehl.*)

Fig. 115.—Diagram of the larger veins and lymphatic vessels of intestine. H, hepatic vein; HP, hepatic portal vein; I, intestine; L, liver; M, mesentery; P, postcava; S, superior cava; TD, thoracic duct, which conveys lymph to the subclavian vein.

can be readily oxidized in the body to carbon dioxide and water. An excess of fat is stored as fat in the tissues.

Absorption and Fate of Carbohydrates.—Monosaccharides, or *hexose* sugars (dextrose), are the final products of carbohydrate digestion. They pass through the walls of the villi into the blood capillaries, whence they are carried by the blood through the portal vein to the liver. In the liver a certain amount of sugar is removed and converted into *glycogen*, an insoluble, starch-like substance that is stored in the liver cells, leaving about 0.15 per cent of sugar in the blood. Sugar, like fat, is an energy producer and is constantly oxidized in the circulation and tissues to carbon dioxide and water. This steady destruction of sugar in the body is made good by the liver reconverting the necessary amount of glycogen into sugar and releasing it into the blood. Beside the liver, glycogen is also stored in muscle and other tissues.

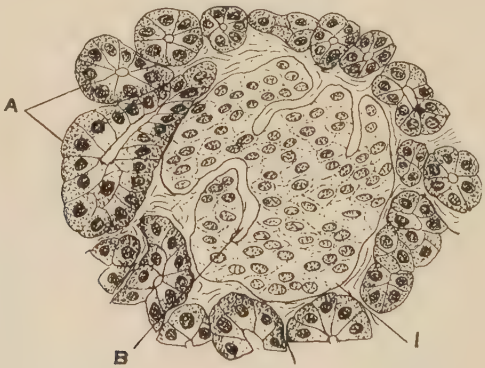


FIG. 116.—Section of an island of Langerhans surrounded by glandular alveoli of pancreas; diagrammatic. A, alveoli of glands drained by pancreatic duct; B, blood vessel; I, island of Langerhans, having no connection with ducts. (*After Stöhr.*)

The pancreas produces a substance known as a *hormone*, given off as an *internal secretion* into the blood. This hormone plays an important part in sugar metabolism, for, if it is kept out of the circulation by removing the pancreas in an experimental animal the percentage of sugar in the blood rises, due to the inability of the tissues to use the sugar. Similar symptoms occur in man in the disease known as *diabetes mellitus;* and since autopsies in such cases frequently show *lesions* in certain cells of the pancreas known as the *islands of Langerhans*, the inference is drawn that the diseased condition of these cells interferes with

the production of the hormone. In fact, *Insulin*, a remedy that has been used with considerable success in the treatment of certain forms of diabetes, is a preparation containing the active principle of the Langerhans cells. The hormone seems to function by *activating* tissue enzymes upon which the oxidation of sugar depends.

Respiration.—Every living cell takes in oxygen and gives off carbon dioxide, the amounts involved varying with the activity of the cell. A muscle at work gives off more carbon dioxide to the blood than one at rest, and takes more oxygen from it. Respiration is a vitally important phase of metabolism.

External Respiration.—In a vertebrate like man external respiration refers to the exchange of gases in the lungs. The composition of the *inspired* air as compared with the *expired* air varies under different conditions and the following data, taken from Howell, must be considered only as approximating the average condition.

	Nitrogen	Oxygen	Carbon Dioxide,
Inspired air..........	79	20.96	0.04 cc. per 100
Expired air...........	79	16.02	4.35 cc. per 100
Difference............	00	4.94	4.34 cc. per 100

The difference in composition of the two kinds of air is due to the fact that the blood in the lung capillaries gives off carbon dioxide and takes in oxygen. If all of the oxygen taken in were breathed out as carbon dioxide, the volume of oxygen lost from the air should equal the volume of carbon dioxide gained, but this is not the case in this particular set of data.

The air taken into the lungs is nearly always cooler than that expired, and the amount of heat lost in this way, varying, of course, with external temperature, is about 50 calories in twenty-four hours.

Inspired air contains less water vapor than expired air, because the latter is nearly saturated with moisture for the temperature at which it leaves the body. The average amount of water lost in this way is 255 grams daily. Since 148 calories are consumed in evaporating this water, respiration becomes an important factor in regulating body temperature, especially in birds, and in mammals, like the dog, which are without sweat glands.

Internal Respiration.—Changes in the gas content of the blood occurring in the course of circulation through the tissues is brought

about by internal respiration. It is the really important phase of respiration. The difference in the composition of the *arterial* blood going to the tissues and the *venous* blood leaving them is as follows:

	Nitrogen	Oxygen	Carbon Dioxide,
Arterial blood........	1.7	20.0	38.0 cc. per 100
Venous blood.........	1.7	12.0	45.0 cc. per 100
Difference............	0.0	8.	7. cc. per 100

The tissues gain oxygen and lose carbon dioxide, and the bright-scarlet color of the arterial blood changes to dark purple.

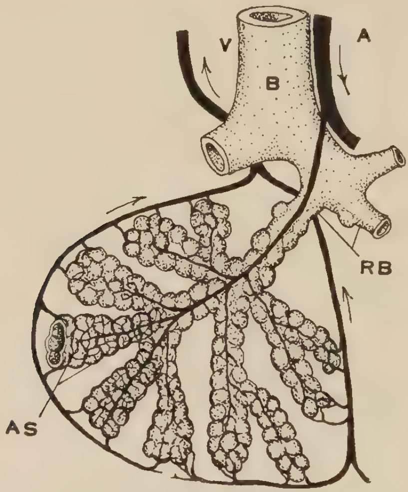


Fig. 117.—Diagram of lung lobule of man showing the relation of the respiratory epithelium to blood vessels. A, artery; AS, alveolar sacs of an alveolar duct whose end is cut off showing the air cavity within; B, bronchus; RB, respiratory bronchus; V, vein. (*After Stöhr.*)

Oxygen of the Blood.—If exposed to air, 100 cubic centimeters of blood *plasma*, or *blood serum* (plasma *minus* fibrinogen, one of the blood proteins), like an equal amount of water, absorb 0.56 cubic centimeters of oxygen at 20° C., at sea level. The amount absorbed depends upon the *partial pressure* of the oxygen in the air. On the other hand, if *defibrinated blood* (blood from which fibrinogen has been removed, leaving corpuscles and serum) is exposed to air, it absorbs practically as much oxygen as it can be made to absorb under any conditions. Thus, if the partial pressure of the oxygen is doubled, only as much additional oxygen will be absorbed as the *serum* can hold, and this amount is very small. If the partial pressure of the oxygen is reduced one-

half, only a small amount is given off, namely, that held by the serum. Since most of the oxygen absorbed by the blood is unaffected by these pressure changes, it must be combined *chemically* in some way with the blood. Since 90 per cent of the dry weight of the red corpuscles is made up of *hemoglobin*, and since this substance when prepared pure is capable of combining with oxygen, it is believed that hemoglobin is the substance which carries most of the oxygen of the blood.

Oxyhemoglobin, the compound formed by oxygen and hemoglobin, is not stable at low pressures, for, if the oxygen pressure to which it is exposed falls below 25 millimeters of mercury, it dissociates completely and suddenly, all of the oxygen being given off. As a result of this property, the blood can take up more oxygen in a short time from the air in the lungs than it could otherwise. It also makes the absorption of oxygen independent of small variations in atmospheric pressure.

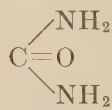
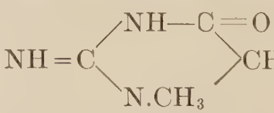
The pressure of oxygen in *saturated* arterial blood is equivalent to the pressure of 100 millimeters of mercury, and, since the oxygen tension of the tissues is zero, oxygen is readily given off to the tissues as the blood circulates through the capillaries. Returning to the lungs with its oxygen tension reduced to 37.6 millimeters, the blood, in passing through the pulmonary capillaries, readily absorbs oxygen from the alveolar air, which has an oxygen tension of 100 millimeters.

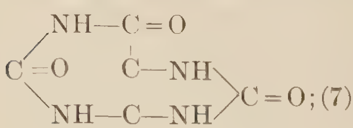
Carbon Dioxide of the Blood.—Carbon dioxide is about twenty times as soluble in blood plasma as is oxygen. In the blood, part of it is held in *solution* in the plasma and the remainder in two forms of *chemical* combination: (1) in the form of sodium carbonate, (2) in combination with blood proteins, including hemoglobin, forming a compound similar to oxyhemoglobin in the readiness with which it dissociates. The tension of the carbon dioxide in the arterial blood entering the capillaries is about 35 millimeters, while that of the lymph and tissues is about 50 to 70 millimeters, so that there is a ready movement of carbon dioxide from the tissues to the blood. The carbon dioxide tension of the blood when it reaches the lungs is 42.6 millimeters, while that of the alveolar air is 35 millimeters, as a result of which carbon dioxide leaves the blood.

Excretion.—Excreta include all waste products of the body. Some of these are metabolic products of substances that were never a part of living tissue, and are therefore known as *exogen-*

ous excreta, such as (1) undigested or unabsorbed food from the alimentary canal; (2) inorganic salts and nitrogenous products of putrefaction absorbed from the alimentary canal by the blood and then excreted without ever becoming a part of living tissue; (3) nitrogen-containing compounds split off from fuel protein in the process of deaminization and eliminated as urea. *Endogenous* excreta, on the other hand, are substances produced by living cells in the course of metabolism. Separate channels for the elimination of these two classes of waste products do not exist, excreta being made up of both kinds. The major part of solid endogenous excreta, and such exogenous excreta as are absorbed by the blood from the alimentary canal, are excreted by the kidneys, while the endogenous excreta contained in bile, such as bile pigments derived from broken-down red blood cells, and cholestrin leave by way of the rectum.

The *kidney* is the principal organ for the removal of solid excretory products. These products, in solution, are removed from the blood as it circulates through the kidneys as described in Chap. VIII. Water and mineral salts apparently leave the blood as it passes through the *glomeruli*, while the organic constituents leave through the cells of the *tubules*.

Urine consists roughly of about 96 per cent water and 4 per cent dissolved solids. The latter include a wide variety of substances that are both endogenous and exogenous in character, as follows: (1) substances that lend *flavor* to food, but are of no nutritional value; (2) *drugs;* (3) *ethereal sulphates* derived from putrefactive processes in the intestine; (4) *urea,* , comprising one-half of the dissolved substances, most of it being exogenous; (5) *creatinin,* , an endogenous product of muscle metabolism; (6) *purin* bodies, endogenous products, of which one of the best known is *uric acid,*

; (7) *salts,* sodium chloride, and sulphates

of sodium and potassium, acid phosphates of sodium, potassium, calcium, and magnesium.

A summary of the metabolism of organic food constituents is shown in the following diagram:

Food constituent	Digestive product	Utilization	Excretion
Protein	Amino acids	Tissue →	Nitrogenous compounds
		Energy →	Urea, CO_2, H_2O
		Fat →	CO_2, H_2O
Fat	Glycerin and soaps	Energy →	CO_2, H_2O
		Fat →	CO_2, H_2O
Carbohydrates	Dextrose	Energy →	CO_2, H_2O
		Fat →	CO_2, H_2O
Vitamines	?	?	?

Metabolism, a Chemical Process.—In general, a review of the principal features of digestion, absorbtion, circulation, and excretion, such as has been outlined in the preceding paragraphs, leaves one with a strong impression of the essentially *chemical* nature of metabolic processes; and this *modus operandi* of metabolism is the strongest argument for believing in the mechanistic theory of life as the only trustworthy guide in biological research. However, while many of the reactions that occur in protoplasm are of a chemical nature similar to those of reactions taking place in test tubes, at the same time others are not so easy to duplicate *in vitro.* There is still much to be learned about the chemistry of protoplasm before the complete explanation of life on a purely *physicochemical basis* will be possible. To mention briefly but one of the stumbling blocks to such an achievement, it may be pointed out that it has not yet been possible to *synthesize* protein, that is, to reconstruct the protein molecule from known chemical substances. The percentage composition of protein can be determined by analysis, but the problem of making this substance out of raw materials has so far not met with success. It is also a peculiarity of metabolic chemistry that oxidizing reactions are carried out at relatively

low temperatures. For example, sugar or fat can be easily oxidized outside of the body, with the evolution of heat. When these substances are burned in the body, the same reactions take place, but at a lower temperature. These and other facts point to the existence of certain factors in the chemistry of living matter that have not yet been clearly explained, but do not discourage the hope that some day their exact nature will be revealed in the laboratory. In this connection it might be pointed out that Baly, an English chemist, has recently succeeded in practically duplicating the *photosynthesis* of plants by building up complex carbohydrates and nitrogen-containing compounds resembling proteins out of simple substances like carbonic acid and potassium nitrate under the influence of ultraviolet light.

References

Bayliss, W. M.: "Principle of General Physiology." Longmans, Green & Company, 1915.

Burton-Opitz, R.: "Elementary Physiology," W. B. Saunders & Company, 1922.

Effront and Prescott: "Biochemical Catalysts in Life and Industry." John Wiley & Sons, 1917.

Howell, W. H.: "Textbook of Physiology," W. B. Saunders & Company, 1922.

Martin, H. N.: "Human Body," Henry Holt & Company, 1910.

Mathews, A. P.: "Physiological Chemistry," William Wood & Company, 1916.

CHAPTER XII

ENDOCRINE SECRETIONS

The endocrine function of an organ refers to the specific rôle of its *internal secretion* in the general metabolism of the body. It should be clear from what has been said that the functional activity of cells in widely separated parts of the body is often dependent upon their receiving from the blood, substances produced by cells in still other parts of the body. Not only does each organ make an indispensable contribution to the economy of the whole, but some organs have the unique function of supplying *specific* reagents that effect one or more organs in a specific manner. Thus, the liver takes from the blood certain substances which, after undergoing various transformations, are secreted as bile into the intestine and utilized in the digestion of fats. At the same time, the liver takes other substances, such as sugar and nitrogenous compounds, from the blood and transforms them into glycogen and urea respectively, later returning them to the blood as sugar and urea. Bile is the *external* secretion of the liver, while sugar and urea are its *internal* secretions. Similarly, the pancreas, as has been noted, produces a substance that is necessary for the oxidation of sugar, but this substance, instead of being poured into the intestine along with the pancreatic juice—its external secretion—is absorbed by the blood as an internal secretion. Products of this kind which stimulate the activity of special organs are known as *hormones* or *endocrine* secretions.

It is the special function of the *ductless* or *endocrine glands* to produce internal secretions that are of supreme importance in coordinating the activities of different parts of the body. No duct being present, such glands pour their product directly into the blood or lymph stream. In the following paragraphs the nature of the functional activity of some of the principal ductless glands are briefly reviewed.

Thyroid Gland.—Arising as an outgrowth of the floor of the pharynx with which it later loses all connection, the thyroid

gland consists usually of two lobes, widely separated in the case of the frog, but joined by a narrow isthmus across the anterior end of the trachea in man. Microscopic examination shows the gland to be made up of a large number of *follicles* of a more or less spherical shape and filled with a mucilaginous secretion known as *colloid.* For its size, the thyroid has a richer supply of blood than any other organ.

Atrophy (degeneration) of the thyroid cells in children induces *cretinism,* which is characterized by an arrested growth of the body and a defective mental development. If dried thyroid gland of the sheep is fed to cretins, there is a tendency toward establishing normal men-

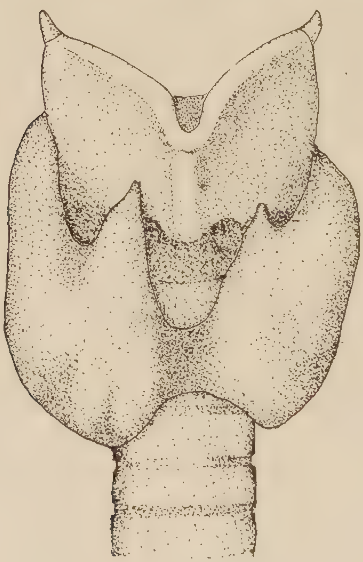


FIG. 118.—Diagrammatic view of human thyroid gland in position against anterior end of trachea.

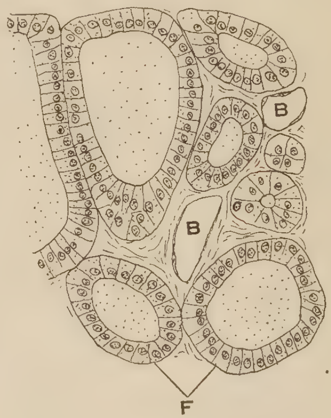


FIG. 119.—Section of human thyroid gland. B, blood vessels; F, follicles filled with colloid. (*After Stöhr.*)

tal and physical conditions, so long as feeding is continued. It has been learned that if the thyroid glands are removed from young frog-tadpoles, differentiation of the limbs and other parts normally accompanying the *metamorphosis* of the larva into the adult fail to occur. The tadpole grows in size but does not change into a frog; but if dried thyroid is given to such animals, metamorphosis takes place. This is but one of many experiments which demonstrate that at least one of the functions of thyroid secretion is concerned with processes of differentiation and development. An extract of the

thyroid gland, known as *thyroiodin*, contains 9.3 per cent of iodine. It has also been found that iodine alone or in organic combination produces a similar effect on thyroidless tadpoles as feeding sheep thyroid or thyroiodin. A crystalline compound, *thyroxin*, having the formula $C_{11}H_{10}O_3N.I_3$, and containing 60 per cent of iodine, was isolated in 1914 by Kendall. Its action on the body is similar to that of thyroiodin.

Hypertrophy (enlargement) of the thyroid gland results in an increased nervous irritability, a condition which may be relieved, as would be expected, by surgical removal of a portion of the gland. *Goitre* is a general term referring to a pathological condition in which the thyroid is enlarged. However, in some forms of goitre the amount of functional thyroid tissue may be much less than in the normal gland. In *exophthalmic goitre* there is an excessive amount of the thyroid hormone, which is accompanied by heightened nervous activity as a result.

As far as is known, the general effect of the thyroid secretion is the stimulation of metabolic processes by increasing the rate of *oxidation* in the body. A substance having such properties obviously plays a part in developing and controlling the physical and mental state of an individual, the importance of which can be scarcely overestimated.

Adrenal Glands.—As the name indicates, the adrenal glands are located near the kidneys, but have no other relation to them. In the frog, the gland consists of a long, narrow band, of a conspicuous orange color, embedded in the ventral face of each kidney. In man, each is a triangular-shaped organ capping the anterior end of the kidney. Since death results when the adrenals are rendered functionless, it is evident that they contribute something to the body that is necessary to life. One of the active principles of the gland has been isolated and is known as *adrenalin*, a substance having the formula $C_9H_{13}NO_3$. It is produced by the *medullary* part of the gland and its function is to maintain a certain degree of contraction in the muscles of blood vessels, the condition called *tone*. It also increases the general sensitivity of muscle to stimulation. The capacity of adrenalin to cause the muscles in the walls of blood vessels to contract is put to practical use in stopping bleeding and thus controlling hemorrhage in surgical operations.

Pituitary Body.—Attached to the ventral surface of the diencephalon the pituitary body consists of two general regions: a large

anterior lobe derived from the ectoderm of the embryonic oral cavity, from which it is pinched off, and a smaller *posterior lobe* arising as an evagination of the floor of the forebrain. The anterior lobe has a distinctly glandular character, but no duct. A *tumor* or hypertrophy of the anterior lobe is usually associated with *acromegaly*, a disease in which there is marked hypertrophy of the bones of the face and extremities. Removal of the anterior lobe in tadpoles prevents metamorphosis. Extracts from the anterior lobes injected into pituitaryless tadpoles bring about metamorphosis, thus indicating that it supplies an *activator* for the thyroid gland. Extracts of the

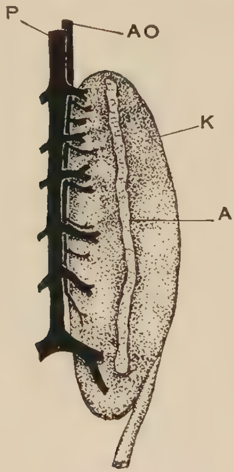


FIG. 120.—Adrenal gland of frog, in position on ventral face of kidney. A, adrenal; AO, aorta; P, postcava; K, kidney.

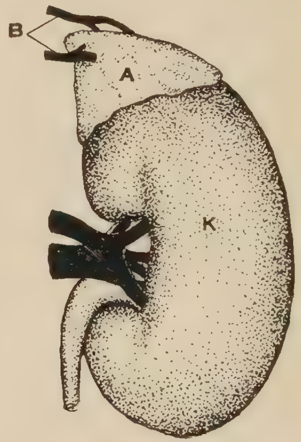


FIG. 121.—Human adrenal gland and kidney, somewhat diagrammatic. A, adrenal; B, adrenal blood vessels; K, kidney.

posterior lobe have in the past not always been free of other tissue juices, so that there has been considerable confusion about the significance of this part of the pituitary. More recently, pure extracts of the posterior lobe have been made which act specifically upon the kidney, diminishing the secretion of urine. Such a substance should have an important use in treating certain forms of diabetes as a control for *diuresis*, excessive secretion of urine. (Roundtree.)

Thymus Gland.—In young mammals the thymus gland extends down into the thorax, overlying the pericardium and is a derivative of the embryonic pharynx. It increases in size until puberty

is reached, after which it undergoes atrophic changes, so that in the adult it is usually difficult to find even traces of it. One would expect, therefore, to find some sort of *reciprocal* functional relationship between the thymus and the reproductive organs, and this proves to be the case. If young mammals are *castrated* (testes removed) there is a persistent growth of the thymus, whereas, on the other hand, removal of the thymus hastens the development of the reproductive organs. There is also reason to believe that the thymus gland in its earlier history has a *hematopoietic* function, that is, it is one of the places in the embryo where blood cells are formed.

There is however some difference of opinion as to the function of the thymus. Thus, Halnan and Marshall in 1914 reported that although castration in young guinea pigs is followed by hypertrophy of the thymus, removal of the thymus, in young animals, has no effect on growth and fails to cause hypertrophy of the testes. The exact rôle of the thymus in metabolism is still an open question.

Organs of Reproduction.—In addition to producing eggs or spermatozoa, the organs of reproduction secrete into the bloodstream substances which effect other parts of the body. Thus, removal of the testes in sheep prevents the development of horns; or removal of the ovaries in fowls causes the hen to assume, to a considerable extent, *secondary sexual* characteristics of the cock. In general, it seems that the internal secretion of the reproductive organs control the development of secondary sexual characteristics, which are characteristics, other than the ovary or testes, distinguishing male from female, such as *comb*, *wattles*, and *spurs* in the cock, or the *beard*, *voice*, and *body size* and *strength* in man.

General Significance of Endocrine Secretions.—The secretions of the endocrine glands furnish a *chemical mechanism* for the functional coordination of various parts of the body. The other general mechanism for this purpose is the nervous system with its nervous pathways along which impulses are conducted to all parts of the body. Of the two, the chemical method is perhaps the older, *phylogenetically;* but practically it is difficult in the final analysis to draw a sharp line between them, because the functional activity of the nervous system rests upon a chemical basis too. In the nervous system, however, the paths along which nervous impulses travel are used for *one special purpose* only; while in endocrine secretions the vehicle is the blood, which

is the *common vehicle* for all of them. In the nervous system some of the nerves have become highly specialized to perform a single function, as, for example, the optic nerve; in the endocrine system, specific substances of various kinds are received and distributed by the blood stream. The nervous system is like a telephone system made up largely of *private* lines, while in chemical coordination the blood is a *party line* with many stations. Both systems, however, are closely related to each other and lose their individuality in the coordination of the body as a whole.

References

Bayliss, N. M.: "Principles of General Physiology," pp. 713–721, Longmans, Green & Company, 1915.

Brubaker, A. P.: "A Textbook of Human Physiology," pp. 521–542, P. Blakiston's Son Company, 1922.

Mathews, A. P.: "Physiological Chemistry," pp. 640–680, William Wood & Company, 1916.

CHAPTER XIII

CELL DIVISION

The common unit entering into the composition of the structural and functional patterns of the multicellular animal body dwelt upon in the preceding pages is the *cell*. Since tissues and organs are composed of cells, the adjustments and the coordinations discernible in metabolism are really the result of coordinated cellular activity. That the metazoan body as a whole behaves as a unit is due to the *integration* of the functions of the cell units. The manner in which cells reproduce themselves is, therefore, a question of prime importance, and will be considered at this point.

Spontaneous generation of living matter from non-living or *abiogenesis* must have taken place when life made its appearance on the earth in bygone ages; and for a long time it was assumed by men of science that abiogenesis, in the lower organisms at least, still continues. One by one, however, the cases of supposed spontaneous generation were disproved until the origin of bacteria only remained to be explained. This was accomplished by Louis Pasteur (1822 1895), the great French scientist, who laid the foundations of modern *Bacteriology* and who showed beyond a doubt that bacteria form no exception to the rule that all life comes from preexisting life by a process of cell division.

Karyokinesis. Cells reproduce by division, of which the ordinary form is known as *mitosis* or *karyokinesis*. Karyokinesis is a continuous process, which, for convenience, has been analyzed in terms of progressive stages as follows:

Resting Stage.—When a cell is not dividing, it said to be in the resting stage, though, as a matter of fact, at the time it may be actively performing its functional rôle in the body economy, and be resting only in the sense that it is not dividing. As seen in prepared sections of adult tissues, the cell in the resting stage shows a *cytoplasmic area* surrounding a single *nucleus*. Both the cytoplasm and the nucleus are bounded by a membrane. The nucleus contains irregular, faintly stained clumps of *chromatin*,

and often a spherical *nucleolus.* The size and the shape of cells vary considerably in different tissues, as has already been pointed out. In an embryo or in other developing tissue a number of cells may always be found in stages of mitosis (Fig. 123).

Division Stages.—The preparatory steps leading to cell division, usually grouped under the head of *prophase* stages, are initiated by the *centrosomes,* which are two small spherical bodies lying close together in a centrosome area just outside of the nucleus. The first step in mitosis consists in the separation of the centrosomes and the formation of a *mitotic spindle,* which in stained sections appears as delicate threads extending between the centrosomes. *Astral radiations* also develop in the cytoplasm about each centrosome. The chromatin of the nucleus meanwhile condenses in a deeply staining coiled thread or *spireme.* The outline of the nucleus now becomes irregular and the nuclear

FIG. 122.—Mitotic figures in cells of larval salamander as they appear in an ordinary section of the skin. × 900.

membrane gradually dissolves. The nucleolus disappears and the spireme breaks up into a definite number of segments called *chromosomes.* The centrosomes move farther apart while the enlarging spindle gradually shifts to the center of the cell. As soon as the chromosomes are formed they migrate to the spindle, upon which they gradually become arranged in the form of an *equatorial plate,* lying in the equatorial plane of the spindle, a stage known as the *mesophase.* Each chromosome then undergoes a longitudinal split (*metaphase*) and the two daughter groups thus formed move away from each other along the fibers of the spindle toward their respective poles. The appearance of the division figure at this point suggests that the chromosomes are pulled apart by fibers attached to the poles of the spindle, but nothing final is known as to the mechanism. At about this time each centrosome undergoes division into two which remain close together. The actual shape of the chromosomes varies

in different animals—sometimes they are short or long rods, but frequently they are V-shaped. In the division of the V the splitting begins at the apex and extends along each arm until two V's are formed (Fig. 123*G*). Sometimes the splitting of the

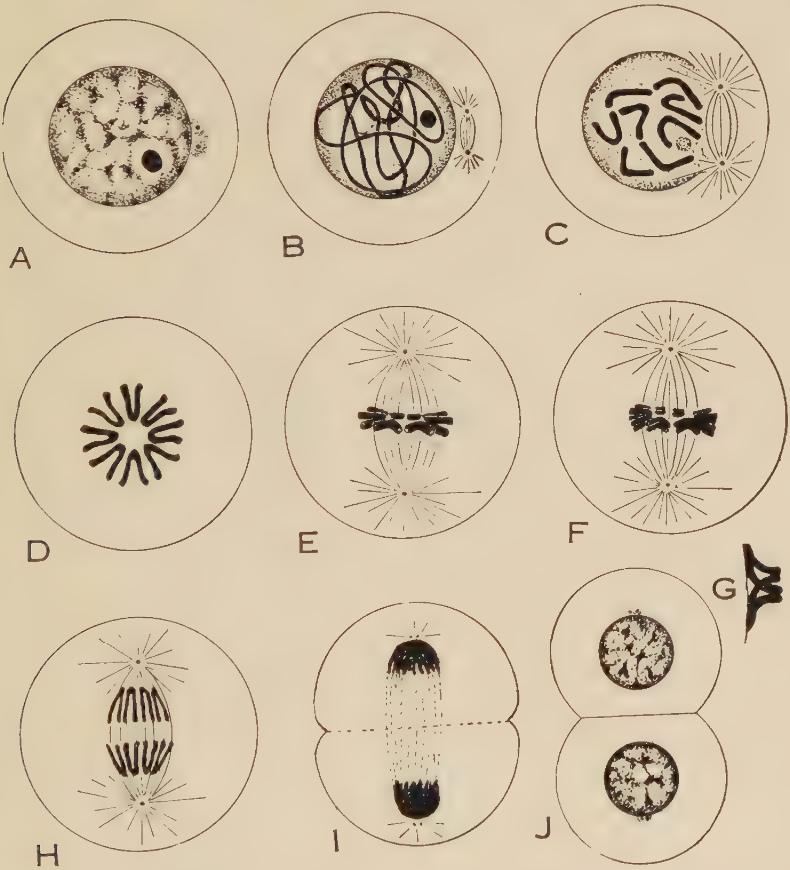


FIG. 123.—Diagram of karyokinesis. A, resting stage, two centrosomes in cytoplasm near nucleus; B, early prophase, spireme stage; C, later prophase, spireme segmented into eight chromosomes; D, polar view of chromosomes at mesophase; E, side view of spindle and chromosomes at mesophase; F, metaphase, each chromosome shows a lengthwise split; G, side view of a single chromosome dividing, early anaphase; H, anaphase; I, telophase; J, two complete daughter cells.

chromosomes is foreshadowed in the spireme stage by the spireme exhibiting a longitudinal fissure, and frequently each chromosome shows a *bipartite* appearance before reaching the equatorial plate.

The *anaphase* includes the stages following the metaphase up to the point where each of the two equal daughter groups of chromosomes forms a dense mass about each pole of the spindle, which marks the beginning of the *telophase*, the final step in cell division. Meanwhile a constriction appears in the cytoplasm in a plane at right angle to the axis of the spindle and gradually cuts the cell into two equal masses. The spindle fibers and the astral radiations slowly fade away, and each group of the chromosomes becomes the center of the formation of a typical resting nucleus, the net result being two complete cells.

The centrosomes, centrospheres, asters, and spindle are spoken of as the *achromatic* structures. These constitute the principal external evidence of the mechanism for bringing about mitosis, one of the principal features of which is the exact distribution of chromosomes to the daughter cells. It is true, of course,

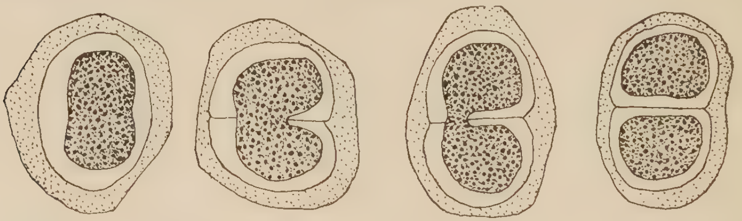


FIG. 124.—Amitosis in nurse cells of ovary of the potato beetle, *Leptinotarsa signaticollis*.

that cells or tissues ordinarily used for the study of mitosis consist of material that has undergone special treatment with reagents and stains, previous to mounting on a glass slide for examination under the microscope, so that, as has been claimed, some of the structures seen in such preparations are possibly artifacts caused by precipitation or coagulation by reagents. This, however is not entirely the case, since a spindle region and chromosomes can be seen in some *living cells*, although the fibers are not visible. Possibly the spindle fibers represent temporary lines of force and stress, since the spindle when dissected out, appears as a definite structure to which the chromosomes adhere as viscous, jelly-like masses but the fibers cannot be seen.

In the adult animal, cell division is confined to some unspecialized cell groups whose function is to replenish loss, such renewals taking place in the majority of the tissues throughout life. Thus the *germinative* layer of the epithelium of the skin is con-

stantly reproducing new cells by mitosis to replace those lost at the surface. Some adult cells, like the red blood cells, or the nerve cells of mammals, never undergo cell division.

Amitosis.—Though simpler in its details, *amitosis* is a much rarer form of cell division than mitosis. There has been controversy as to its occurrence and nature, but the question cannot be properly discussed here. Amitosis has been described in various tissues under normal conditions, and in *degenerating* cells and in *pathological* tissues, but it is clear that it is not the ordinary method of cell division. Figures of cells dividing amitotically show each constituent of the cell, beginning with the nucleus, dividing into two by simple constriction, none of the complex apparatus of mitosis being involved.

References

DONCASTER, L.: "An Introduction to the Study of Cytology," Cambridge University Press. 1920.

SHARP, L. W.: "An Introduction to Cytology," McGraw-Hill Book Company, Inc. 1921.

WILSON, E. B.: "The Cell in Development and Heredity." The Macmillan Co., 1925.

CHAPTER XIV

GAMETOGENESIS

Since all cells are derived from preexisting cells by cell division, it follows that a line of continuity, a *cell lineage*, extends from the

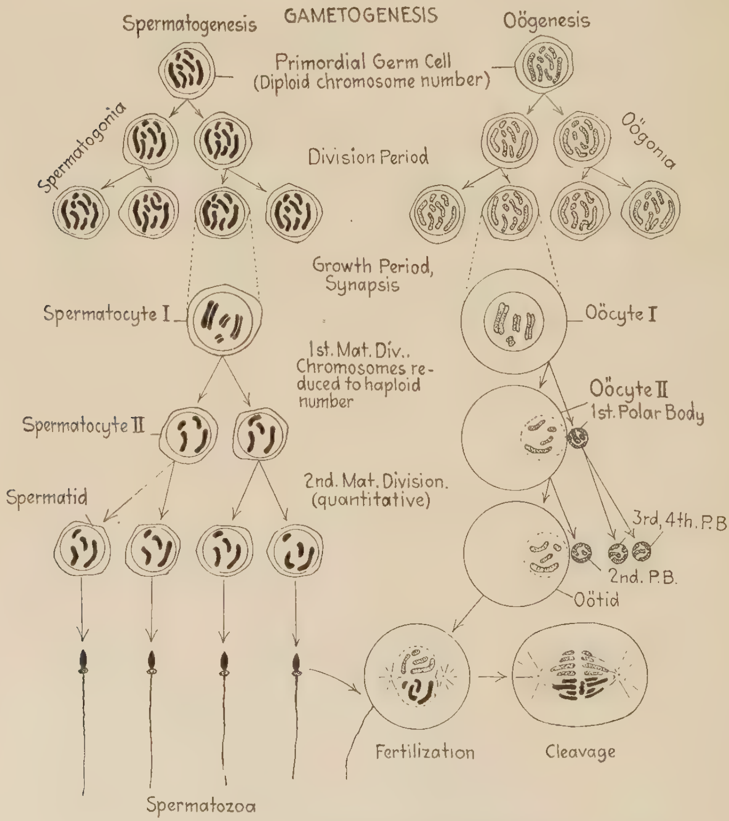


FIG. 125.—Diagram of gametogenesis, fertilization and cleavage.

first appearance of simple unicellular organisms down through all forms of life of today. Reproduction in Protozoa consists, for the most part, of the division of the cell into one or more parts,

each of which develops into a new animal. In multicellular animals, the egg and the sperm are merely cells of the body that have the power, when united in fertilization, to develop into a new organism by a process of cell division accompanied by differentiation.

In many cases of metazoans the germ cells or *gametes* are differentiated relatively early in embryogeny from the somatic or body cells, but they do not achieve their full development until the onset of sexual maturity. The *primordial germ cell* is the first of these cells to be distinguished as the immediate ances-

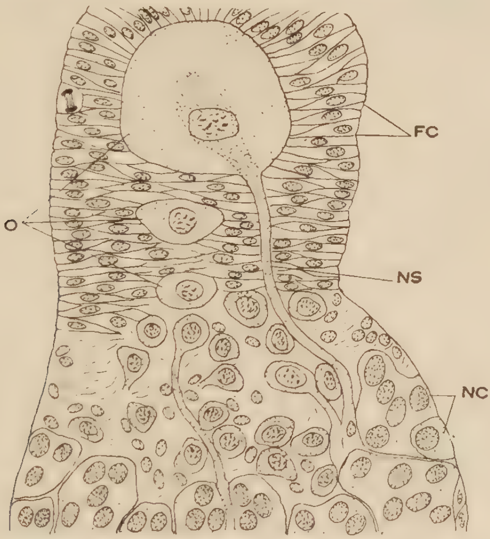


Fig. 126.—Longitudinal section of an ovariole showing how nutrition is supplied to the egg of the potato-beetle, *Leptinotarsa signaticollis* (growth period) NC, nurse cells; NS, nutritive string; O, oöcytes; FC, follicle cells.

tor of all of the germ cells produced in the body of an animal. *Gametogenesis* refers to all changes and transformations undergone by the primordial germ cell and its descendants in the production of functional eggs and spermatozoa, *oögenesis* having to do with the development of the ova or eggs in the ovary, and *spermatogenesis* with the formation of spermatozoa in the testis. Both processes are alike in their general outlines but differ somewhat in details.

Oögenesis.—In oögenesis there is formed, as a result of a number of rapid mitotic cell divisions beginning with the primordial germ cell, a large number of *oögonia*, only a few of which

are represented in the diagram. Some of the last generation of oögonia then enter upon a period of growth, which finally results in their transformation into cells of large size known as *primary oöcytes.* Others of the oögonia do not undergo growth, but serve as *nurse cells* for the oöcytes. The large size of the latter is the result of the deposition of yolk or reserve stuff in the cytoplasm. In the *first maturation* division, which follows the growth period, the primary oöcyte divides into two

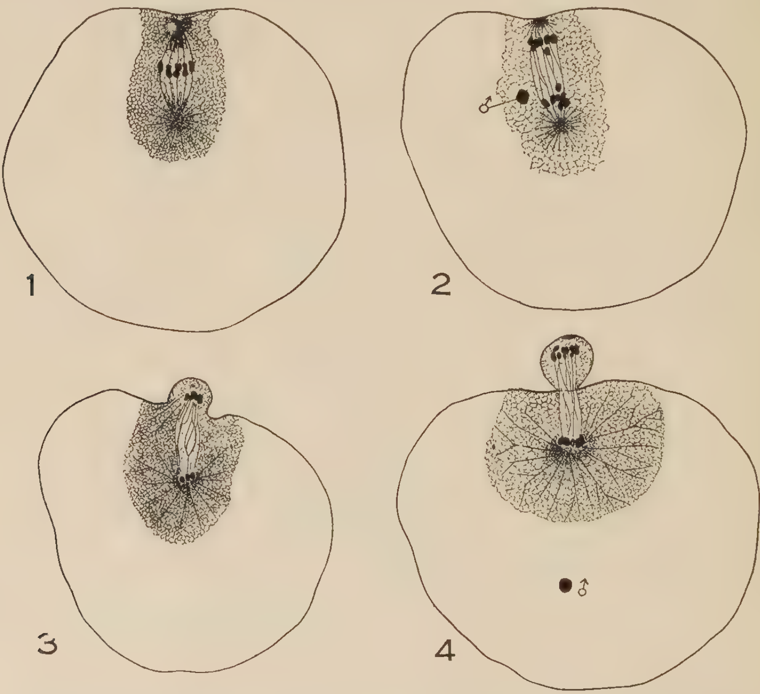


FIG. 127.—Four stages in the formation of the first polar body in the egg of *Planocera inquilina.* ♂, sperm nucleus. (*From Patterson and Wieman.*)

cells of unequal size, the larger one being called the *secondary oöcyte,* and the smaller the *first polar body.* In a *second maturation* division the *secondary oöcyte* also divides into two cells of unequal size, the larger of which is the *oötid,* and the smaller the *second polar body.* At the same time, the first polar body divides to form the *third* and *fourth polar bodies.* Therefore, as a result of the two maturation divisions, a primary oöcyte produces four cells: one oötid, which is the mature ovum, and three small

polar bodies. The polar bodies remain for a time attached to the egg at the point where they are extruded, but later they are lost and play no further part in development. It is generally supposed that the polar bodies are potentially the same as ova, but lack sufficient cytoplasm for development. This view is supported by some observations by Francotte on the development of certain flatworms in which he found that when fertilization of the first polar body is brought about experimentally the polar body develops as far as the *gastrula* stage. Development up to a certain point is possible in this case because the first polar body is very large. In most animals it is very small and consists of but little more than a nucleus.

Spermatogenesis.—In this process the daughter cells of the primordial germ cell are known as *spermatogonia.* The last generation of these also pass through a growth period, but it is not so extensive as in the case of the oögonia and a larger number of cells participate. Growth transforms spermatogonia into *primary spermatocytes.* In the first maturation division each primary spermatocyte produces two *secondary spermatocytes* of equal size. Likewise, in the second maturation division each secondary spermatocyte divides to form *two spermatids* of equal size. Thus, each primary spermatocyte produces four spermatids. Each spermatid then undergoes further development into a *spermatozoön.* In this transformation the chromatin of the nucleus of the spermatid is crowded into the head of the spermatozoön, while the middle piece and tail of the latter are formed from the cytoplasm of the spermatid.

Chromosomes.—What is perhaps the most important feature of gametogenesis, namely, the behavior of the chromosomes, may now be considered. Assuming that the nucleus of the primordial germ cell contains *eight* chromosomes, in each of the mitotic divisions of the division period *eight* chromosomes appear on the spindle and are evenly divided between the daughter cells. During the growth period, the nucleus has the typical appearance of the resting stage, the chromosomes losing their identity. When the prophase figures develop at the end of the growth period, instead of eight, only *four* chromosomes appear, but each of the four is a double or a *bivalent* chromosome composed of two single or univalent ones. This pairing of the chromosomes is known as *synapsis* and takes place during the growth period in both oögenesis and spermatogenesis. (Fig. 125.)

Reduction.—Owing to constant differences in form and size, it is possible to arrange the chromosomes of the presynaptic period into two series of four each, in this case. In synapsis these chromosomes pair off according to form, size, or other characteristics to form the bivalent chromosomes of the first maturation spindle. Only *homologous* chromosomes combine with one another. In the first maturation division the bivalent chromosomes are divided so as to produce two groups of univalent chromosomes; *i.e.*, a real *reduction* from the *diploid* number, eight, to the *haploid* number, four, takes place. This, therefore, is called a *qualitative* or *reduction* division. In the second maturation division each of the four univalent chromosomes splits lengthwise as in ordinary mitosis, so that the oötids or spermatids each receive four univalent chromosomes. This is called a *quantitative* division. In some cases, apparently, the quantitative division comes first; but in any event the final result is the same—the oötid, polar bodies, and spermatids all receive the haploid number of chromosomes. The egg and the sperm, then, each carry the haploid number of chromosomes, so that at fertilization the diploid number is restored. Further, since the cells of the embryo, and later the adult, are produced by cell division from the fertilized egg, each cell of the body comes to have the diploid number of chromosomes. From this it follows that every cell in the body except the germ cells of postreduction stages is possessed of a *maternal* and a *paternal* series of chromosomes. This fact is of the utmost importance in understanding the mechanism of heredity, in which connection it is considered in a later chapter.

Sex Chromosomes.—In the foregoing it has been assumed that the number of chromosomes is the same in both sexes, but in many cases the number of the female differs from that of the male. Thus, in the common squash bug, *Anasa tristis*, the diploid number of the female is *twenty-two*, while that of the male is *twenty-one*. In oögenesis the number is reduced to eleven, as would be expected, and all eggs therefore receive *eleven* chromosomes. In the male, on the other hand, owing to the uneven diploid number, *two classes* of spermatozoa are produced, one containing *ten* and the other *eleven* chromosomes. A male must, therefore, be produced when a sperm containing ten chromosomes fertilizes an egg (10 + 11 = 21), and a female when a sperm containing eleven chromosomes fertilizes an egg (11 +

11 = 22). In Anasa, apparently, the presence or the absence of the extra chromosome determines sex, for which reason it is called the *sex chromosome*. It is also known as the X chromosome, *odd* chromosome, or *accessory* chromosome. The remaining chromosomes, which are equally represented in both sexes, are known as *autosomes*.

FIG. 128.—Chromosomes of the squash bug, *Anasa tristis*. *a*, polar view of equatorial plate, first spermatocyte; *b*, side view of anaphase, second spermatocyte; the heterochromosome (*h*) passes undivided to one pole of spindle; *c* and *d* show the result of the second spermatocyte division, ten chromosomes going to one cell (*c*) and eleven to the other (*d*), so that two classes of spermatozoa result; *e*, polar view of spermatogonium showing twenty-one chromosomes; *f*, diploid chromosome complex of male arranged in pairs according to size, and forming a bi-parental series; *g*, polar view of equatorial plate of oogonium showing twenty-two chromosomes; *h*, diploid complex of female, paired according to size. (*From Wilson, Journal of Experimental Zoology.*)

An inspection of the chromosomes of Anasa shows that the diploid complex of the male, as seen in the spermatogonial division figures, can be arranged into a series of *ten* synaptic pairs of autosomes plus *one* X chromosome, which lacks a synaptic mate in the male. In the female there are *ten* synaptic pairs of autosomes, corresponding to those of the male, plus *two* X chromosomes. The difference, then, in the sex chromosome complex

is that the female has two X chromosomes, while the male has but one.

Reduction Division in Anasa.—The behavior of the chromosomes in the spermatogenesis of Anasa is as follows: Twenty-one chromosomes appear on the spindles of the spermatogonia. During the rest period the X chromosome persists as a *chromosome nucleolus*, while the twenty autosomes lose their identity. In the prophase of the first spermatocyte, eleven chromosomes, consisting of ten bivalent autosomes and the X chromosome, appear. In the subsequent division, all divide so that each secondary spermatocyte receives eleven chromosomes (10 autosomes + X). In the second maturation division all of the autosomes divide, the X chromosome passing undivided to one pole of the spindle. The result is that one-half of the spermatids receive ten autosomes, and the other half ten autosomes plus one X chromosome, a total of eleven.

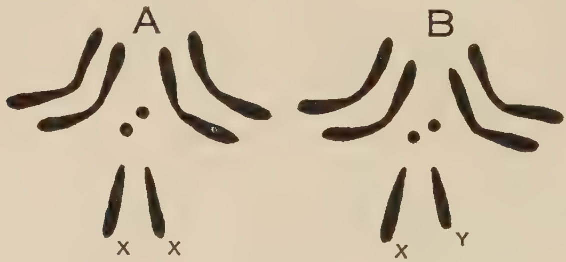


FIG. 129.—The chromosomes of the fruit-fly, *Drosophila ampelophila*. A, female; B, male. (*After Metz.*)

Sex Determination.—Inequality in the male and female chromosome complexes seems to prevail in practically all animals. Frequently, as in Anasa, the inequality lies in a difference in number, but in other cases it consists of a difference in size of one or more of the sex chromosomes. For example, in the common fruit fly *Drosophila ampelophila*, the diploid number is eight in both sexes, but the chromosomes of the female is made up of six autosomes plus *two* X chromosomes, while that of the male consists of six autosomes plus *one* X and *one* Y chromosome. The difference between the male and female then in this case is the difference between X and Y, X being larger than Y. In view of such facts it is difficult to avoid the conclusion that there is a very definite connection between *sex determination* and the *distribution* of the sex chromosomes.

CHAPTER XV

ONTOGENESIS

The development of the individual is known as *ontogenesis*, while *phylogenesis* refers to the development of the race. Since the history of a race is composed of a number of individual life

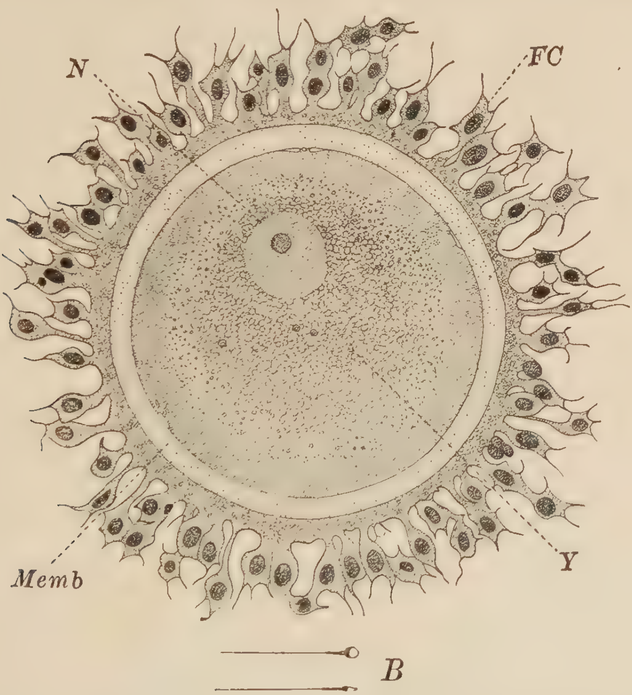


Fig. 130.—A, nearly ripe human ovum in the living condition. The ovum is surrounded by follicle cell (*FC*) inside of which is the clear membrane (*Memb*) and within this is the ovum proper containing yolk granules (*Y*) and a nucleus (*N*) embedded in a clear mass of cytoplasm. Magnified 500. B, two human spermatozoa drawn to about the same scale of magnification. (*From Conklin, Heredity and Environment, Princeton University Press. A, after O. Hertwig; B after G. Retzius. By permission.*)

histories, ontogenesis and phylogenesis are merely different aspects of the same process, namely, development. So far as the individual is concerned, sperm and ovum form the basic

elements out of which it is evolved, while individuals, in turn, form the elements of the race.

Germ Cells.—The *egg* is a relatively large cell whose bulk is due to the presence in the cytoplasm of a greater or less amount of yolk, which is energy stored in the form of foodstuff by virtue of which the fertilized egg develops into an embryo. In strong contrast to the egg the *spermatozoön* is a very small cell, without yolk, and in most cases capable of energetic movements by means

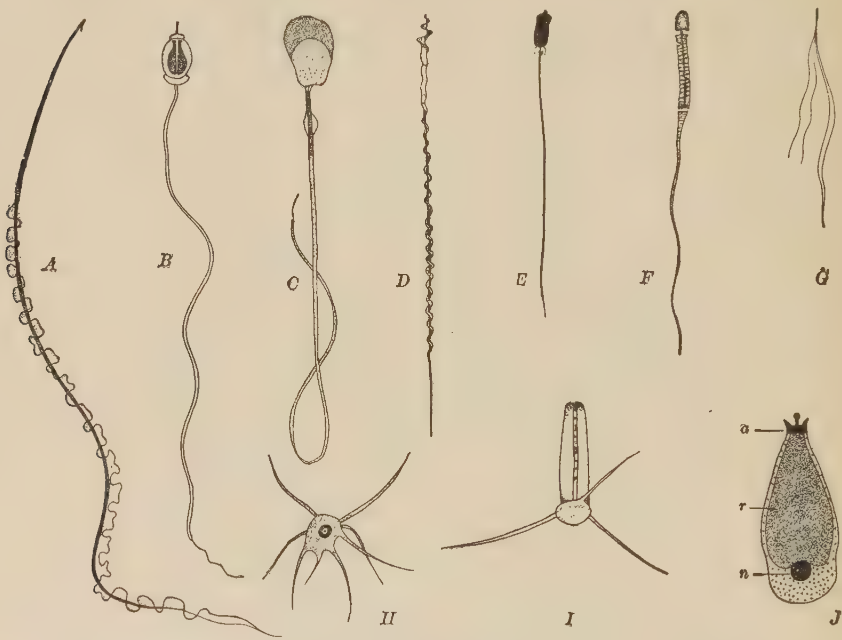


FIG. 131.—Types of spermatozoa. A, salamander. (*After Ballowitz.*) B, annelid (*Nereis*). (*After Lillie.*) *C*, guinea pig. (*After Meves.*) *D*, bird (*Phyllopneuste*). (*After Ballowitz.*) *E*, sturgeon. (*After Ballowitz.*) *F*, bat. (*After Ballowitz.*) *G*, turbellarian (*Castrada*). (*After Luther.*) *H*, crustacean (*Pinnotheres*). (*After Koltzoff.*) *I*, crustacean (*Homarus*). (*After Herrick.*) *J*, nematode (*Ascaris*). (*After Scheben.*) *a*, apical body; *h*, nucleus; *r*, refractive body. (*From Sharp, Introduction to Cytology.*)

of a flagellum or tail. In some forms—*crustaceans*, for example—a tail is lacking, in consequence of which the sperm cells in these cases are incapable of rapid locomotion. The head of the sperm in all cases contains the chromatin contribution of the male parent.

Fertilization.—If mature sea urchin or starfish eggs are placed on a glass slide under the microscope and a drop of sea water

containing ripe sperm from the male added, one can readily see that almost at once each egg becomes surrounded by a vibrating fringe of sperms, each of which seems to be doing its utmost to gain entrance into the egg. The spermatozoa reach the eggs by swimming movements executed by whip-like contractions of the

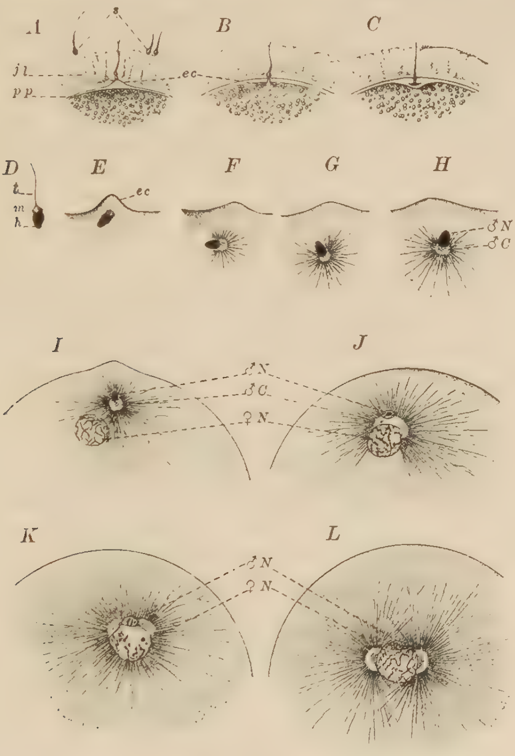


FIG. 132.—Fertilization of the eggs of starfish and sea-urchin. *A–C*, successive stages in the entrance of a spermatozoon into the egg of the starfish, *Asterias glacialis*. Only one sperm has penetrated the jelly layer (*jl*) which surrounds the egg and the peripheral cytoplasm (*pp*) of the egg protrudes as an entrance cone (*ec*) to meet it. (*After Fol.*) *D*, mature spermatozoon of the sea-urchin Toxopneustes, showing head (*h*); middle-piece (*m*); and tail (*t*). *E–H*, successive stages in the penetration of the sperm nucleus (♂*N*) and centrosome (♂*C*) into the egg of *Toxopneustes*. *I–L*, stages in the approach of the sperm nucleus (♂*N*) to the egg nucleus (♀*N*), and in the division of the sperm centrosome (♂*C*) and the formation of the first cleavage spindle. (*D–L after Wilson.*) (*From Conklin, Heredity and Environment, Princeton Univ. Press. By permission.*)

tail, but these mechanical movements of the sperm do not completely account for the results. Thus, Lillie has shown that ripe eggs of a number of marine forms when placed in sea water give off a substance called *fertilizin*, which is necessary for

fertilization; for if this substance is removed from the eggs by repeated washings beforehand, the eggs are not fertilized when normal, active swimming sperms are added to them. There must, therefore, be something in the nature of a *chemical attraction* between the germ cells that is a factor of prime importance in guiding the sperms to the egg.

Entrance of Sperm.—There is no general rule regarding the stage of development reached by the egg before they are laid or fertilized. In some species the eggs are ready for impregnation by sperm, *insemination*, at the primary oöcyte stage, in others

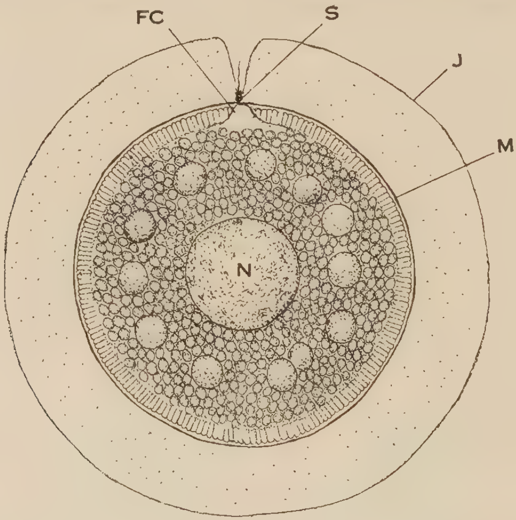


FIG. 133.—The egg of *Nereis* twelve minutes after insemination; the secretion of the jelly is completed, the walls of the emptied alveoli of the cortical layer appearing as radiating lines across the perivitelline space. The spermatozoön lies in the funnel-shaped depression in the jelly; the egg having formed a fertilization cone crossing the perivitelline space and touching the membrane beneath the spermatozoon. FC, fertilization cone; J, jelly; M, egg membrane; S, spermatozoon. (*After Lillie.*)

at the secondary oöcyte stage, while in still others the sperm does not enter the egg until after both polar bodies have been formed. As soon as the sperm touches the *vitelline membrane* bounding the egg the latter undergoes profound changes. Take, for example, *Nereis*, a common marine worm that has been carefully studied by Lillie. When the egg is deposited in the water, it is in the primary oöcyte stage, neither polar body having been formed. The instant a sperm strikes the vitelline membrane, a jelly-like

substance begins to flow out from the cortical region of the egg and continues flowing until the egg is surrounded by a thick gelatinous envelope. The jelly exudate must not be confounded with fertilizin, which is soluble in sea water and is given off inde-

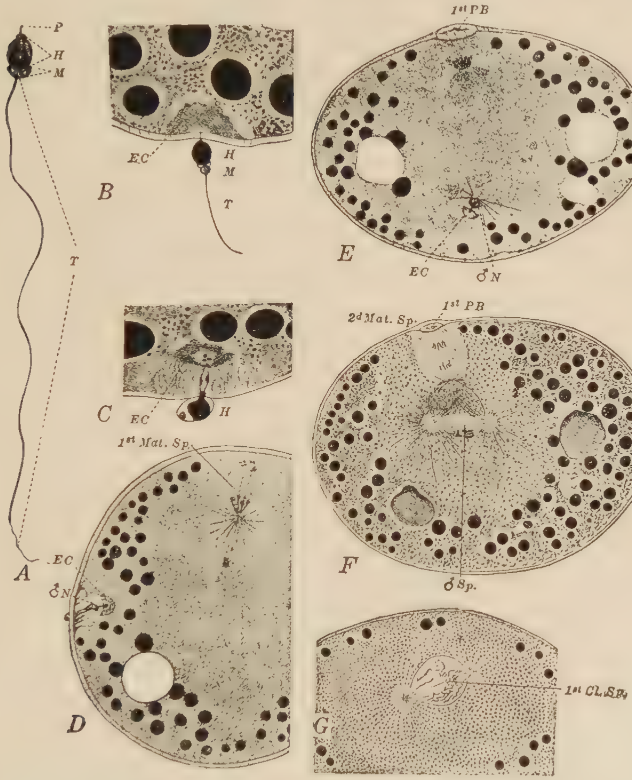


FIG. 134.—Entrance of the spermatozoön into the egg of Nereis. A, entire spermatozoon, showing perforatorium (*P*); head (*H*); middle-piece (*M*); and tail (*T*). B–G, successive stages in maturation and fertilization, showing the progress of the entrance cone (*EC*) and the sperm nucleus (*N*) into the egg. D shows the first maturation spindle (*1st Mat. Sp.*); E the first polar body (*1st PB*) formed by this division; F the second maturation spindle (*2nd Mat. Sp.*) and the sperm nucleus and spindle (♂*N*); G the division of the male and female nuclei in the first cleavage spindle (*1st Cl. Sp.*). (*From Conklin, Heredity and Environment, Princeton Univ. Press, after Lillie. By permission.*)

pendently. Meanwhile, the single successful sperm with its head attached to the vitelline membrane lies in a funnel-like depression in the envelope, the unsuccessful or *supernumerary* sperm having been pushed away from the membrane by the jelly. The overflow of jelly empties *alveoli* in the cortex of the egg, leaving a *peri-*

vitelline space traversed by delicate radiating strands. Soon a small hillock, the *entrance cone,* arises in the protoplasm immediately beneath the point where the spermatozoön is attached and pushes out across the perivitelline space until it touches the membrane. Then the entrance cone retracts and draws the sperm into the egg, the tail and middle piece being left out. Within the egg the sperm head is gradually converted into what is called the *male nucleus.* In the meantime, the first and second polar bodies are formed, and the primary oöcyte is converted

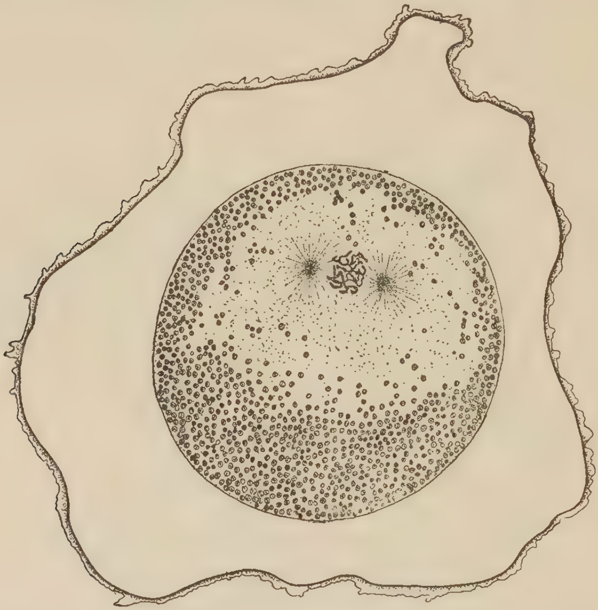


FIG. 135.—Prophase of first cleavage in Amphioxus; the membrane is separated from the egg by a wide perivitelline space. (*From Kellicott, Chordate Development, H. Holt & Co., after Sobotta. By permission.*)

into an oötid. The nucleus of the oödtid and the male nucleus then fuse to form the *fertilization nucleus,* which marks the consummation of the process of fertilization. Next a spindle is formed, the nuclear membrane dissolves, the chromosomes take their places on the spindle, and the egg is ready to undergo its first *cleavage.* It is to be remembered that each nucleus, male and female, contributes one-half of the total number of chromosomes appearing on the first cleavage spindle (unless, of course, the diploid number is uneven).

Cleavage.—In order to illustrate cleavage and following stages in development, take as an example *Amphioxus lanceolatus*, the lancelet, a marine form belonging to the phylum *Chordata*, which is a better illustration than Nereis. The egg of the Amphioxus is *isolecithal*, that is, the yolk is rather uniformly distributed through the egg, although it is more concentrated at one pole, the *vegetative* pole, than at the other, the *animal* pole. Assuming that fertilization has taken place and that the first cleavage spindle has formed, the egg divides into two cells of equal size called *blastomeres*. The plane of the division is *meridional*, that is, it passes from the animal to the vegetative pole. In this and succeeding divisions the diploid number of chromosomes appears on the spindle each time, and each chromosome is evenly divided between the daughter cells. In the second cleavage each of the first two blastomeres is divided, forming four cells of equal size. In the third cleavage the plane is at right angles to the first two, and therefore *equatorial*. The result is eight cells, but the four surrounding the animal pole are slightly smaller than the four at the opposite pole. The process continues until a large number of cells are produced. (Fig. 136.)

Germ Layers.—The blastomeres are gradually arranged in the form of a hollow sphere, the *blastula*, enclosing the cleavage cavity or *blastocœl*. Then the larger cells at one pole of the blastula invaginate to form a double-walled cup, the *gastrula*, the result of which is the obliteration of the blastocœl. The new cavity produced by gastrulation is called the *gastrocœl*, and the opening into it the *blastopore*. The wall of the gastrula is made up of two primitive germ layers, the *ectoderm* outside and *endoderm* inside. The gastrula elongates and the blastopore shifts its position to a point opening on the posterodorsal aspect of the future embryo.

Neural Tube.—In the flattened middorsal region, a strip of ectoderm, the *neural plate*, is gradually separated laterally from the adjacent ectoderm by which it is slowly overgrown and covered, the overgrowth beginning at the ventral lip of the blastopore and extending forward. The edges of the neural plate grow toward each other dorsally and medially to form the neural tube, which opens anteriorly at the *neuropore* and connects posteriorly *via* the blastopore with the archenteron. The connection between the neural tube and the gastrocœl is called the *neurenteric canal*. (Figs. 137, 138.)

Mesoderm.—Meanwhile, the primitive endoderm forming the roof of the gastrocœl gives rise laterally to paired diverticula or *cœlomic pouches,* while the central part separates to form the

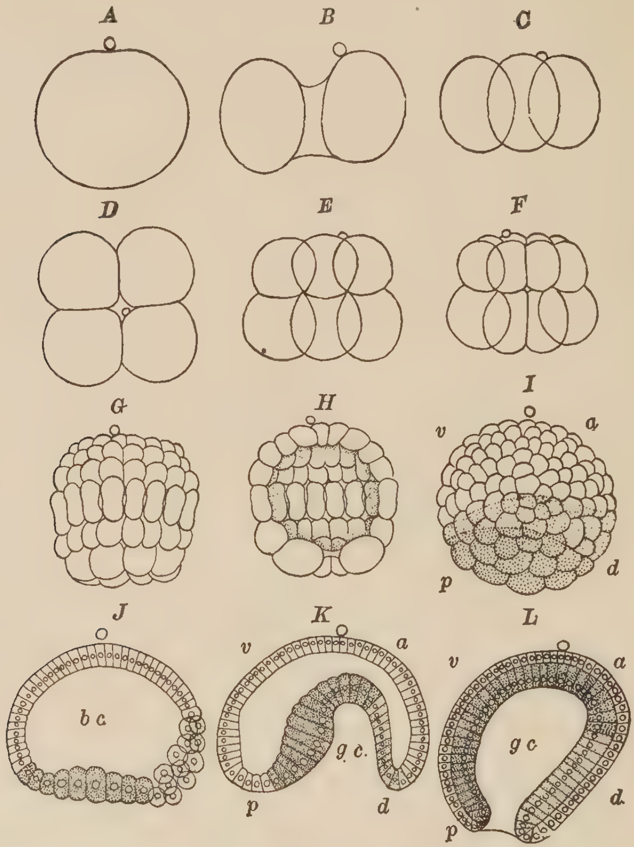


FIG. 136.—Successive stages in cleavage and gastrulation of Amphioxus. *A*, one cell; *B*, two cells; *C* and *D*, four cells; *E*, eight cells; *F*, sixteen cells; *G*, blastula stage of about ninety-six cells; *H*, section through same showing the cleavage cavity (blastocœl); *I*, blastula seen from the left side showing three zones of cells, viz., and upper clear zone of ectoderm, a middle (faintly shaded) zone of mesoderm and a lower (deeply shaded) zone of endoderm cells; *J*, section through same showing these three types of cells; *K* and *L*, successive stages in the infolding of the endoderm. *a*, anterior; *p*, posterior; *v*, ventral; *d*, dorsal; *bc*, blastocœl; *gc*, gastrocœl. (*A–H, after Hatschek.*) (*From Conklin, Heredity and Environment, Princeton Univ. Press. By permission.*)

rod-like *notochord.* The cœlomic pouches, which represent the primary *mesoderm* or third germ layer, become pinched off, forming a series of closed cavities on either side. Later, these give

rise to two unsegmented sheets of mesothelium, the outer or somatic layer of which becomes applied to the ectoderm while

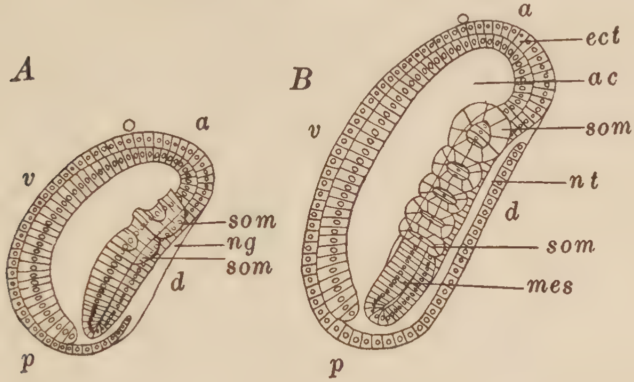


FIG. 137.—Two later stages in the development of Amphioxus, showing the elongation of the embryo in the antero-posterior axis (*a–p*), and formation of somites (*som*); neural groove (*ng*) and neural tube (*nt*); *ect*, ectoderm; *mes*, mesoderm; *ac*, alimentary canal. (*From Conklin, Heredity and Environment, Princeton Univ. Press, after Hatschek. By permission.*)

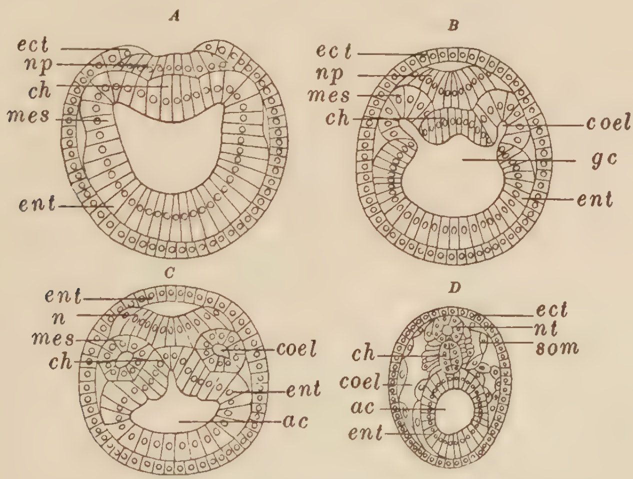


FIG. 138.—Cross sections of Amphioxus larvae in successive stages of development. A, through a larva similar to 137*A*; *B* and *C*, of a larva similar to 137*B*; *D*, of a still older larva. *ect*, ectoderm; *ent*, endoderm; *mes*, mesoderm; *ch*, notochord; *np*, neural plate; *gc*, gastrocœl; *ac*, alimentary canal; *coel.*, cœlom. (*From Conklin, Heredity and Environment, Princeton Univ. Press. By permission.*)

the inner or splanchnic layer envelops the tubular *gut endoderm*, the space between them constituting the *cœlomic cavity*.

Later Development.—During the larval stage of development the only opening of the alimentary canal to the outside is through the neuropore, in and out of which water flows as a result of the action of cilia lining the neural tube. In the transformation of the larva, a *mouth* is formed at the anterior end of the alimentary canal, and an *anal* opening at the posterior end. The neurenteric canal closes. A little later the neuropore also closes, but its location is marked in the adult by the presence of an *olfac-*

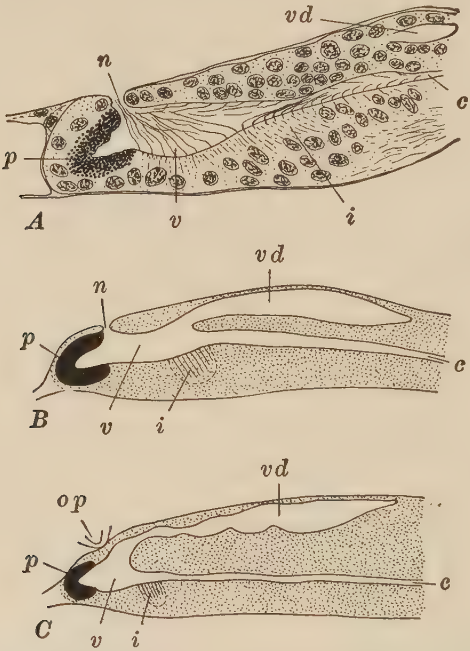


FIG. 139.—Median sagittal sections showing three stages in the development of the brain of Amphioxus. *c*, central canal of cord; *i*, infundibulum; *n*, neuropore; *p*, cerebral pigment; *op*, olfactory pit; *v*, cerebral vesicle; *vd*, postero-dorsal extension of cerebral vesicle. (*From Kellicott, Chordate Development, H. Holt & Co., after Boeke. By permission.*)

tory pit which develops at this point. Just in front of this is formed a pigmented *eyespot*. The anterior end of the neural tube enlarges slightly to form the brain, while the rest of it retains its tubular outline as the spinal cord. The notochord in Amphioxus extends from a point in front of the brain throughout the entire length of the body to its end.

Gill Clefts.—On either side of the body wall in the region of the pharynx, *gill slits* develop as the result of the outward extension

of endodermal *pharyngeal* pouches to the ectoderm, where perforations are produced at the points of contact of the two germ layers. However, these gill slits do not open directly to the outside because of the simultaneous formation of the *atrium*, a chamber developed by a sac-like extension of the body wall enveloping the branchial region. The atrium is closed in front, but has an opening, the *atriopore,* on the midventral side posteriorly. Water enters the mouth, passes through the gill clefts into the atrium and out through the atriopore. Blood flowing through the *gill septa* between the clefts is aerated from the water.

Higher Forms.—The development of Amphioxus outlines the general course of the early development of every vertebrate. The details of cleavage, gastrulation, formation of germ layers, and the later differentiation of tissues and organs, are not, of course, identical with these processes in Amphioxus. For example, in the development of the vertebrate nervous system the neural tube is derived from the dorsal ectoderm, but in its complete development it goes far beyond the point reached by the adult Amphioxus. In the latter the so-called brain is merely the expanded anterior end of the neural tube, while in the vertebrate the brain is made up of five typical regions of considerable size and complexity of structure, which increase with the position of the animal in the vertebrate scale. Superficially, the vertebrate spinal cord remains relatively simple, but compared with Amphioxus it is a highly complex organ. The notochord, which remains the permanent axial skeleton of Amphioxus, develops in the same relative position in the body of the embryo of all vertebrates but, except in the lowest, *Cyclostomata,* it is replaced in the adult in varying degrees by the vertebrae of the spinal column, which with the skull forms the axial skeleton. Gill clefts, or at least pharyngeal pouches, develop in the embryos of all vertebrates, but only in fishes and some amphibians do they persist as permanent structures in connection with the respiratory apparatus. In air-breathing vertebrates all of the gill clefts disappear before the adult stage is reached. The cavity of the first gill pouch persists as the chamber of the *middle ear*, which retains its connection with the pharynx by the *Eustachian tube.*

Law of Biogenesis.—That the circulatory system of the fish should be similar to that of Amphioxus is not perhaps striking; but that the embryonic circulatory system of forms above the fishes should also prove to be built along the same lines is highly

significant. Thus, the heart of the *chick embryo* lies in an antero-ventral position in the body cavity, and pumps the blood forward through a ventral aorta, from which it passes right and left dorsally through aortic arches to a pair of dorsal aortae. The latter convey the blood to all parts of the body, from which it is returned by cardinal veins and common cardinals to the heart,

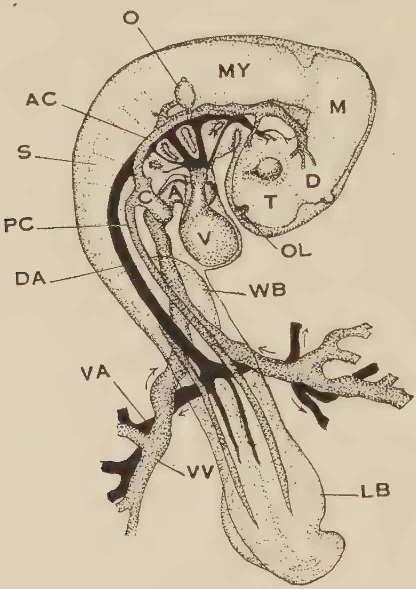


FIG. 140.—Circulatory system of chick embryo of seventy-two hours incubation; embryonic membranes not shown. Starting at the ventricle (V) the blood is pumped forward through the ventral aorta to the aortic arches, of which the four of the right side are shown (in solid black). The gill clefts lie between the arches. Above, the aortic arches unite to form a dorsal aorta each of which sends a carotid artery (right one shown) to the head. Posteriorly, the aortae unite to form the dorsal aorta (DA) which in the middle of the trunk region gives off a right and left vitelline artery (VA) carrying blood to the yolk capillary circulation to be aerated and charged with food from the yolk. The blood returns to the embryo by right and left vitelline veins (VV) which unite and join the sinus venosus of the heart. Blood is collected from the embryo by right and left anterior and posterior cardinal veins (AC, PC) which form on each side a common cardinal (C), also joining the sinus venosus. The mingled venous blood from the cardinal veins and the aerated blood from the vitelline veins passes from the sinus venosus to the atrium (A) and then to the ventricle. D, diencephalon; LB, leg-bud; M, mesencephalon; MY, myelencephaion; O, otic vesicle; OL, olfactory pit; S, somite (muscle); T, telencephalon; WB, wing-bud.

as in the fish. There is also a yolk-sac circulation which serves to aerate the blood and also to supply the embryo with nutrition. The blood in passing through the gill arches is not aerated, since this is done in the yolk sac. The resemblance of the aortic arches

to the fish circulation is merely an anatomical one, and incomplete at that, since no gill capillaries are present. One is forced to the conclusion that the similarity in the circulatory systems of the fish and chick is due to the fact that the higher vertebrate in its development is merely following the path along which its *evolution* took place. This does not mean that an animal in its development repeats every step in its racial history (*phylogeny*)—many steps are slurred over or even omitted—but that ontogeny is, to a *certain extent*, a repetition of phylogeny. This fact is known as the *Law of Biogenesis* and its application to problems in embryology has thrown light on otherwise obscure facts in development.

Homology.—What is true of the vertebrate circulatory system is also true of other organs of the body. Thus, the wings and the legs of birds and the limbs of quadrupeds all develop from *limb buds*, which in their inception are outgrowths of the body wall. The development of the limb buds in the two cases is similar up to a certain point, beyond which the common path diverges into two, one of which leads to the appendages of the bird and the other to those of the quadruped. Embryology thus enables one to determine whether organs are *analogous* or *homologous*. Two organs are said to be homologous when they have the *same method of development*, and analogous when they are *similar in function*. The wings of a bird and the arms of man are homologous but not analogous; the eyes of a squid and those of man are analogous but not homologous; while the arms of man and those of an ape are both homologous and analogous. Homology in organs or parts is then an indication of common ancestry, so that a knowledge of embryogeny not only is very important for its own sake but is indispensable to an understanding of the phylogenetic relationships of animals.

References

Conklin, E. G.: "Heredity and Environment in the Development of Men," pp. 1–91, Princeton University Press 1916.

Kellicott, W. E.: "General Embryology," H. Holt & Company, 1913.

Kellicott, W. E.: "Chordate Development," H. Holt & Company, 1913.

Lillie, F. R.: "The Development of the Chick," H. Holt & Company, 1919.

Lillie, F. R : "Problems of Fertilization," Univ. of Chicago Press, 1919.

Morgan, T. H.: "The Development of the Frog's Egg," The Macmillan Company, 1897.

CHAPTER XVI

THE EVIDENCE FOR EVOLUTION

Organic evolution implies *descent* in living things—that higher forms of animals and plants have evolved from lower forms, which were the more immediate descendants of the first living things to appear on the earth. The organic world is divided into two great subdivisions, the animal kingdom and the plant kingdom, which, taken as a whole, are easily distinguishable,

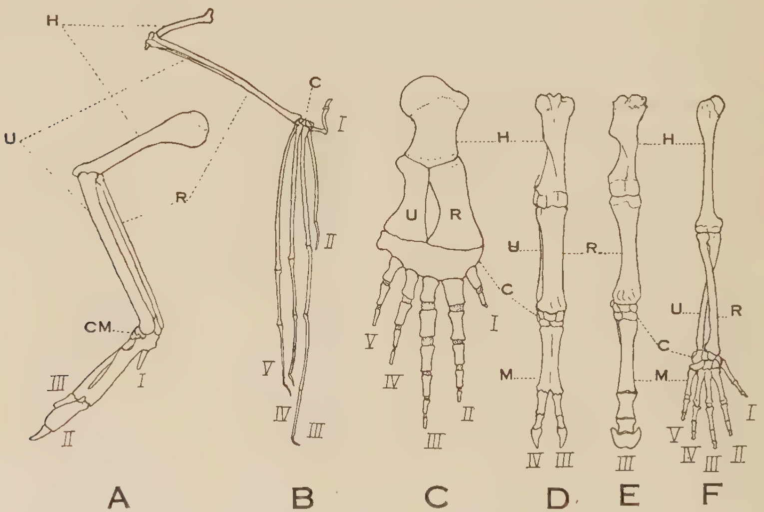


FIG. 141.—Skeleton of the right forelimb of several vertebrates to show the fundamental similarity of structure. A, bird (raven); B, bat; C, whale; D, ox; E, horse; F, man. C, carpals; CM, carpometatarsal; H, humerus; M, metacarpals; R, radius; U, ulna; I–V, digits. (*Modified from Scott, The Theory of Evolution, copyright, The Macmillan Co. By permission.*)

since one usually does not have much difficulty in telling an animal from a plant. But at the lower end of the scale in each group the features that mark animals from plants are not so easy to determine, for here one finds animal-like plants and plant-like animals. Such intermediate forms constitute the connecting links between animals and plants, and, presumably,

represent organisms that have diverged least from the first forms of life. *Protista*, all unicellular organisms, are the living organisms nearest to the theoretical primitive protoplasm.

Morphological Evidence.—In the animal kingdom morphological evidence for evolution is based on observed structural resemblances and differences in animal groups. Such studies show the persistence of the same organs or parts, changed and sometimes distorted for different uses, but still referable to common morphological units. Animals can be arranged in a series beginning with *Protozoa* and ascending step by step in ever-growing complexity of structure to *Vertebrata* at the top of the scale. Strictly speaking, the series is not smoothly graded—gaps occur here and there—and for some animals it is a question as to just where they should be placed in the scheme; but as time goes on these gaps are being bridged by the discovery of new facts, which warrant the assignment of uncertain groups to definite places. The systematic arrangement of animals, based on natural relationships, is an evidence of evolution of the highest value.

Embryological Evidence.—In many cases the proper classification of the adult animal has depended upon a knowledge of its embryo genesis. Aside from special instances where embryology has been a deciding factor in determining a correct classification, the method of development of the Metazoa is based on a general plan that is shared by all of them. Thus, the *cell*, which forms the entire body of the protozoan, is the starting point in the development of all higher animals. *Cleavage*, the period of cell proliferation following fertilization of the egg, occurs in the early development of all Metazoa. It leads, in turn, to the formation of *blastula* and *gastrula*, and the genesis of the *germ layers*. Cœlenterates go very little beyond the development of two germ layers; and Hydra in its adult stage is but little more than a tube of ectoderm lined with endoderm, with just the beginning of a trace of a third germ layer, the mesoglœa, between them. One might say, therefore, that the development of Hydra had been arrested at the two-germ-layer stage. Higher forms, on the other hand, pass through and beyond a diploblastic condition and add a third layer, the mesoderm, the three germ layers serving as the point of departure for the differentiation of the tissues and organs of the embryo and, later, the adult. *Gastrulation* is a fundamental process in the development of all Metazoa.

The evidence for evolution supplied by embryological studies is perhaps more convincing if attention is confined to a single group of animals, as, for example, the Vertebrata, all of which possess a *vertebral column* or backbone. Other evidences of relationship were noted in a preceding chapter where, among other things, it was pointed out that the general layout of the circulatory system of all vertebrates has its model in the fish circulatory system, and that, in general, the higher forms in their development repeat to a certain extent structural features of lower forms. The occurrence of a *fish-like type of circulatory*

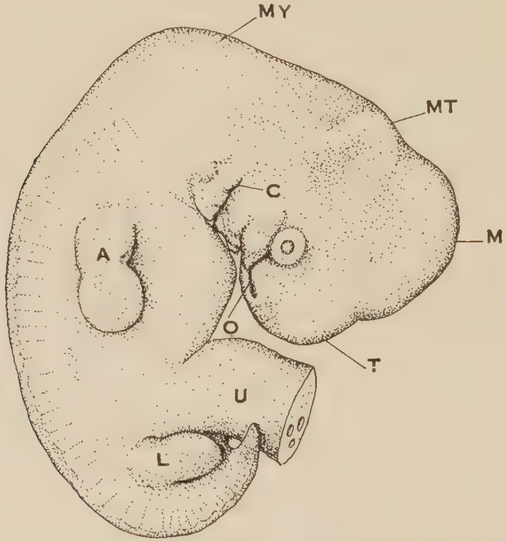


FIG. 142.—Human embryo of about thirty days in age. A, arm-bud; C, gill cleft (hyomandibular); L, leg-bud; M, mesencephalon; MT, metencephalon; MY, myelencephalon; O, olfactory pit; T, telencephalon; U, umbilical cord. (*After Keibel and Mall, Human Embryology, J. B. Lippincott Company.*)

system in the embryo of a higher vertebrate would seem to point to the origin of the latter from a fish-like ancestor. At the same time it must be remembered that the embryonic circulatory system of the chick or man can be compared only with the circulatory system of the *fish embryo*, rather than that of the adult. The close resemblance between the chick circulation and that of the adult fish is due to the fact that the fish has diverged only slightly from the primitive vertebrate type of circulation. What is true of the circulatory system is found to be true also of other organs of the chick which pass through developmental

stages that are to be regarded as embryonic survivals. Embryos of birds and reptiles have gill slits today because gill slits were present in the embryos of their ancestors.

Physiological Evidence.—In general, protoplasm shows considerable *plasticity;* that is, it can be molded or changed within certain limits. Thus, for example, anyone unacquainted with the history of the various breeds of domestic pigeons would say without hesitation that the differences between some of the breeds were at least of the magnitude of species differences; yet as Darwin first pointed out they have all been derived by a process of selective breeding from a single wild species, *Columbia*

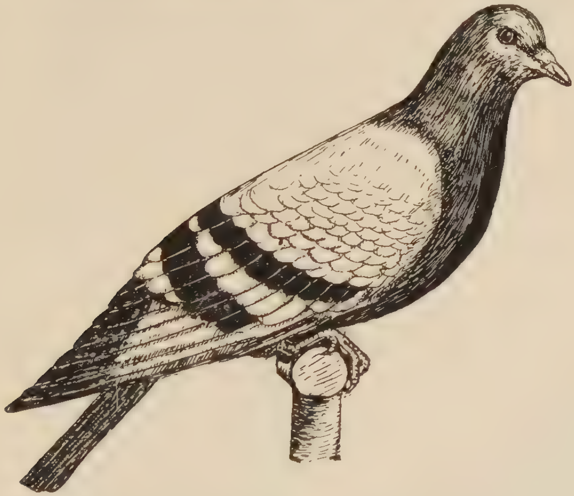


FIG. 143.—*Columba livia*, the ancestor of 150 or more varieties of domestic pigeons. (*After Whitman, Carnegie Inst. Pub.*)

livia, the rock pigeon. A common breed, the *fantail,* possesses something like forty tail feathers, whereas the ordinary pigeon has but sixteen. In all probability the former was derived from the latter by taking advantage of chance variations in tail feathers, and selecting for breeding only those birds showing an abnormally large number, until the present fantail was produced.

The same thing is true of *domestic animals* generally. The breeder obtains desired results by carefully watching for favorable variations in his stock and then breeding only the favored animals. In this way in a relatively short space of time the various standard breeds of dogs, horses, and cattle have been

produced and, likewise, the different varieties of each of many fruits, vegetables, and grains. Selective breeding is mainly

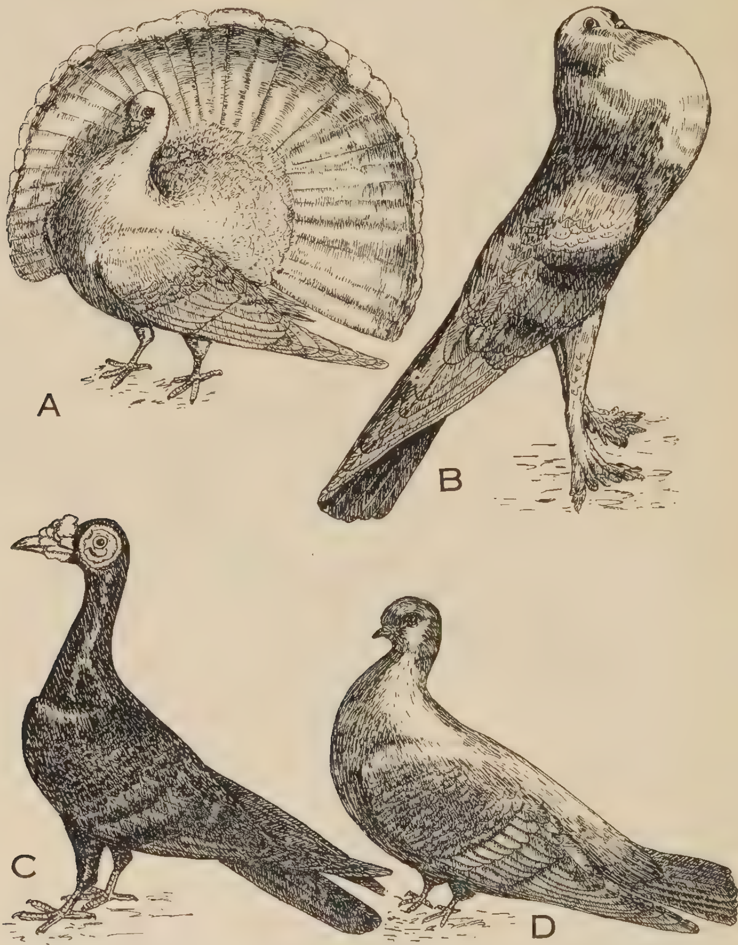


Fig. 144.—A few of the domestic varieties of pigeons. A, English Fantail; 30–40 tail-feathers; small feet. B, English Pouter; short beak, upright posture, inflated crop. C, English Carrier; elongated beak, neck and body, corrunculated skin surrounding the eyes. D, short faced English Tumbler; small beak, feet and body; tumbling habit (tumbles backward, involuntarily, during flight). (*Redrawn from Darwin, Animals and Plants under Domestication, D. Appleton & Co. By permission.*)

responsible for these results, even though in some cases, as in dogs, two or more ancestral species are believed to be involved.

Constant *selection* must be practiced or the breed will revert *toward* the ancestral or unimproved type. Thus, among pigeons an occasional rock type will appear in an otherwise standard brood, showing that, after all, the well-established domestic breeds are not very far removed from the common ancestor. Likewise, if domestic breeds are allowed to run wild, they very soon lose their distinguishing characters and *tend* to become similar to, though not necessarily actually like, the wild forms from which they were derived.

Artificial Selection.—By taking advantage of chance *variations*, artificial selection is capable of producing remarkable varieties in a species, and these varieties can be maintained if constant

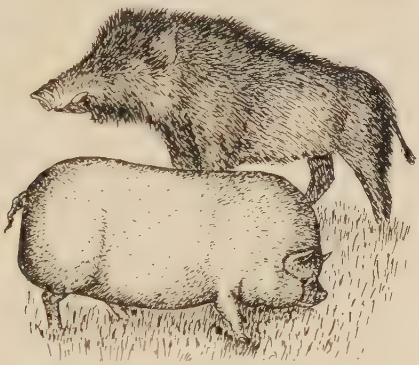


FIG. 145.—Domestic pig with its wild boar ancestor. (*After Romanes, Darwin and after Darwinism, Open Court Publishing Company.*)

selection is practiced. Such experience shows that protoplasm has the capacity for modification, the plasticity, that is assumed as a fundamental basis for evolutionary processes. At the same time this does not mean that there are not limitations to variations and therefore to the extent to which selective breeding can be successfully carried out. These limits are discussed somewhat in detail in the following chapter.

Serum Tests.—Another sort of physiological evidence for evolution is furnished by serum tests, which enable one to measure much more accurately than by any other method the degree of *blood relationship* existing between animals. If human blood serum, blood *minus* corpuscles and fibrinogen is injected in small quantities at repeated intervals in the blood vessels of a rabbit, there is developed after a while in the blood of the latter substances known as *antihuman* bodies. The antihuman proper-

ties developed in the rabbit blood are manifested by the production of a precipitate when antihuman rabbit serum is added to *normal* human serum in a test tube. Now if *antiape* rabbit serum is prepared in the same way, and is added to normal human serum, a precipitate is again produced, but not in as great amount as when human and antihuman serum are brought together. If *antidog* serum is tested, it produces a precipitate with human serum, but still less in amount than that produced by antiape

FIG. 146.—*Archaeopteryx macura*, restored. The fossil remains of this link between reptiles and birds was found in the Jurassic of Bavaria. The jaws do not have a beak but are provided with teeth. The tail consists of about 20 separate vertebrae to which feathers are attached on either side. Each wing has 4 clawed fingers. Feathers are well-developed on the wings and tail but the head and other parts of the body are naked. The bones are without air-sacs. (*After Romanes, Darwin and after Darwinism, Open Court Publishing Company.*)

with human serum. In general, when the serum reactions of two animals are tested with a third, the one whose antiserum produces the greater precipitate with the normal serum of the third is the one which is more closely related to the third. From such experiments the important fact emerges that the degree of relationship as ascertained by ordinary methods of classification, based largely on morphological data, is borne out by the reactions of the blood. In these experiments the rabbit figures

merely as a laboratory for manufacturing the antiserum. A guinea pig or other laboratory animal might be used equally well.

Paleontology.—The evidence derived from the study of the remains of ancient extinct animals and plants furnishes important and convincing proof that living things have changed from time to time, steadily progressing from the simpler to the more complex. With animals, these remains that have survived the ravages of time—in some cases for millions of years—are the hard skeletal parts. Naturally, the evidence is often fragmentary, and the wonder is that so much has been preserved rather than so little. Despite tremendous difficulties, paleontologists have been remarkably successful in tracing back the history of animals—some much more completely than others—but, even where the lines of descent have not been cleared up, the study of fossils has always shed light on the relationships of living groups. As has been mentioned before, the system of classification may be likened to a tree, of which the terminal twigs alone represent the living fauna. The larger branches and trunk are all dead, and

TABLE 2.—GEOLOGICAL TABLE.

In the following table the latest time is at the top and the earliest at the bottom. The term "era" refers to intervals separated from one another by marked changes in the earth's plant and animal life; "periods" are separated by geological changes principally. The duration of eras is based on a total of approximately 500,000,000 years as the age of the earth, probably a very conservative estimate.

Psychozoic Era. 25,000 to 30,000 years. Includes the present time during which man attained his highest development. The age of human predominance.

Cenozoic Era. 20,000,000 years. Age of mammals. Includes the last ice age.

Mesozoic Era. 55,000,000 years. Age of reptiles.

Cretaceous Period. Primitive mammals; flowering plants.

Jurassic Period. Toothed birds; flying reptiles.

Triassic Period. Dinosaurs; reptile-like mammals.

Paleozoic Era. 150,000,000 years. Age of fishes.

Permian Period. Land vertebrates; modern insects. An ice age.

Carboniferous Period. Sharks; coal deposits.

Devonian Period. Marine fishes; amphibians; land plants.

Silurian Period. Lung fishes.

Ordovician Period. Fresh water fishes.

Cambrian Period. Invertebrates.

Pre-Cambrian Era. 275,000,000 years. Early forms of life. Includes two ice ages. (After Schuchert.)

whatever record exists of these parts is in the form of fossil remains. Consequently, the discovery of remains of any kind is valuable, and if such remains belong near the terminal branches of the tree, they are useful in solving questions of relationship among their living descendants. The table on page 193 is a resumé of the geological periods in the earth's history, which gives some idea of the age and distribution of the principal animal groups of animals and plants in the order of their appearance and duration.

Evolution of the Horse.—The ancient history of the horse, to mention but one example, is now known with such completeness as to be practically beyond question. Its ancestry has been traced back to an animal that lived 3,000,000 years ago and left its remains in *Cenozoic* rocks. It is known as *Hyracotherium*. It was the size of a fox, and had four toes and a rudiment of another on its forefeet, and three toes on its hind feet. In later strata occur the remains of *Protorohippus*, an animal somewhat larger than Hyracotherium, with four toes on its fore feet and three behind. Next in the series is *Mesohippus*, the size of a sheep, with three toes and a rudiment of a fourth on its fore feet and three on its hind feet, the middle toe on all feet being somewhat larger than the others. *Protohippus*, the next link, was the size of a donkey, and had but one well-developed toe and two rudimentary ones on each foot. Finally, the modern horse, *Equus*, is a larger animal than any of the preceding, having a large single well-developed toe and two very rudimentary splints on each foot. The fossil remains also show important and interesting changes in the character of the teeth and other parts of the body, some of which are shown in the figure.

Similar paleontological records of other forms show beyond a doubt that animals, and plants, too, have changed in character since the beginning of life on the earth. They prove that animals of today were not created as such in the beginning, but have gradually changed through long periods of time, passing through many transformations before modern species were produced. In general, there is an increase in the number of species in the more recent layers of rock and a convergence toward common types the farther back one goes.

Zoögeography.—In their geographical distribution animals are found to be adapted to the general conditions of climate, geography, and environment under which they live. It is not

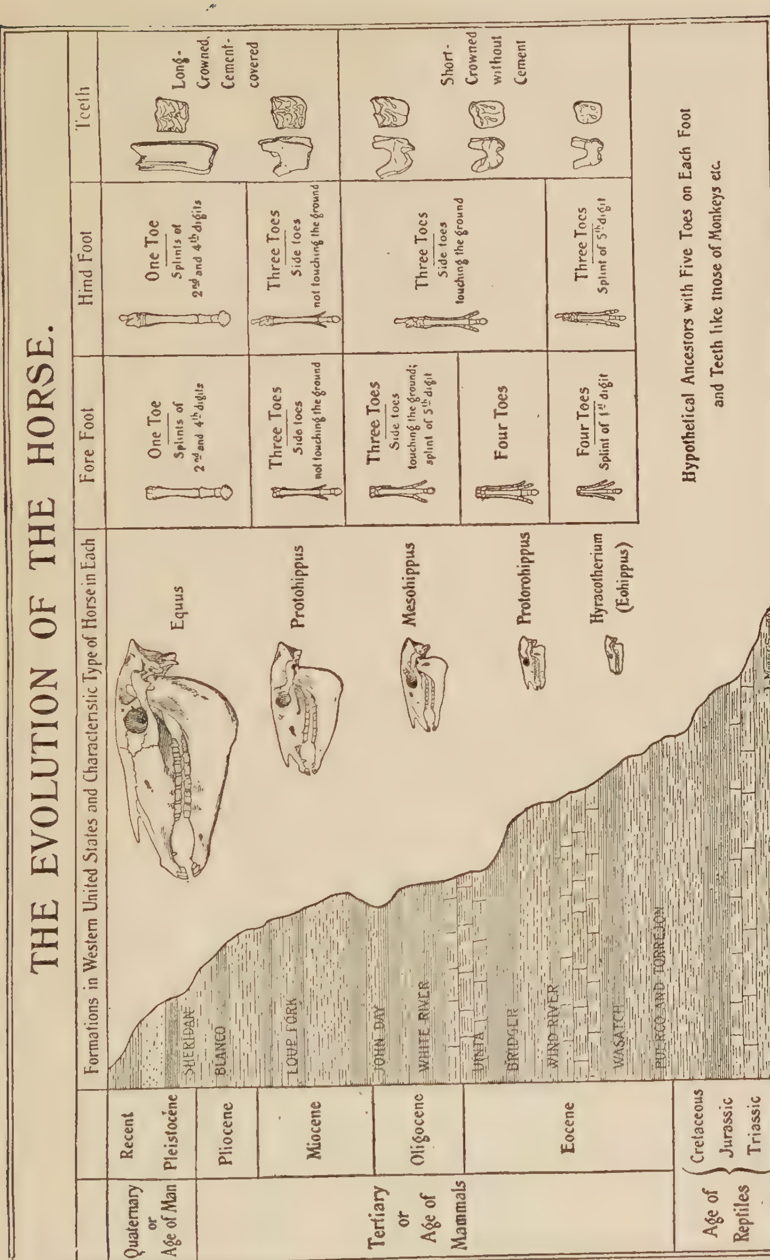


FIG. 147.—Graphic outlines of the evolution of the horse. (From Osborn. By permission of author and the American Museum of Natural History.)

surprising, therefore, that representative of the same group of animals should be found living under similar conditions in different parts of the world. However, the fact that, when transplanted, animals can live just as well in habitats far removed from their native haunts suggests that the explanation of animal distribution involves something more than the matter of adaptation. Through human agency the rabbit was introduced into Australia, where it found conditions so much to its liking that it thrived to the extent of becoming a real pest. If conditions in Australia were so favorable to the rabbit, why is it that this species of animal was not found there as a native? Or, to take the other side of the question, why is it that the native fauna of Australia includes such primitive mammals as the *duckbill* and the *kangaroo*, but that none of these mammals are found living under similar climatic conditions in other parts of the world? Similar questions arise in cases of the discontinuous distribution of members of the same group of animals in widely separated parts of the world. Thus, the *tapirs*, pig-like mammals are found in Central and South America, and southern Asia; one genus of the *camel* family exists in central Asia and northern Africa, while other members of the same family are represented by the *llama* and *vicuna* in South America; *alligators* are found in central China and southeastern United States, etc. Why have these and other animals failed to occupy all the stations in life favorable for their support?

Paleontology, in affording evidence for evolution in general, also throws light on the problem of the discontinuous distribution of animals. Paleontology shows that animal groups often originated in localities far removed from the present habitats of their living descendants. Fossil remains of the camel show that the group formerly ranged North America as well as Asia, a fact that can be readily understood when it is remembered that these two continents were formerly connected where Bering Strait now separates them. Camels survived in Asia whence they spread to Africa, but became extinct in North America. No living horse is a native of North America, yet it is known from remains that the horse passed its early development there and spread to the Old World, where it survived. The history of many animals, including man, shows evidence of wanderings from place to place, in search of food, in all probability, until the paths of these various migrations have become a complicated

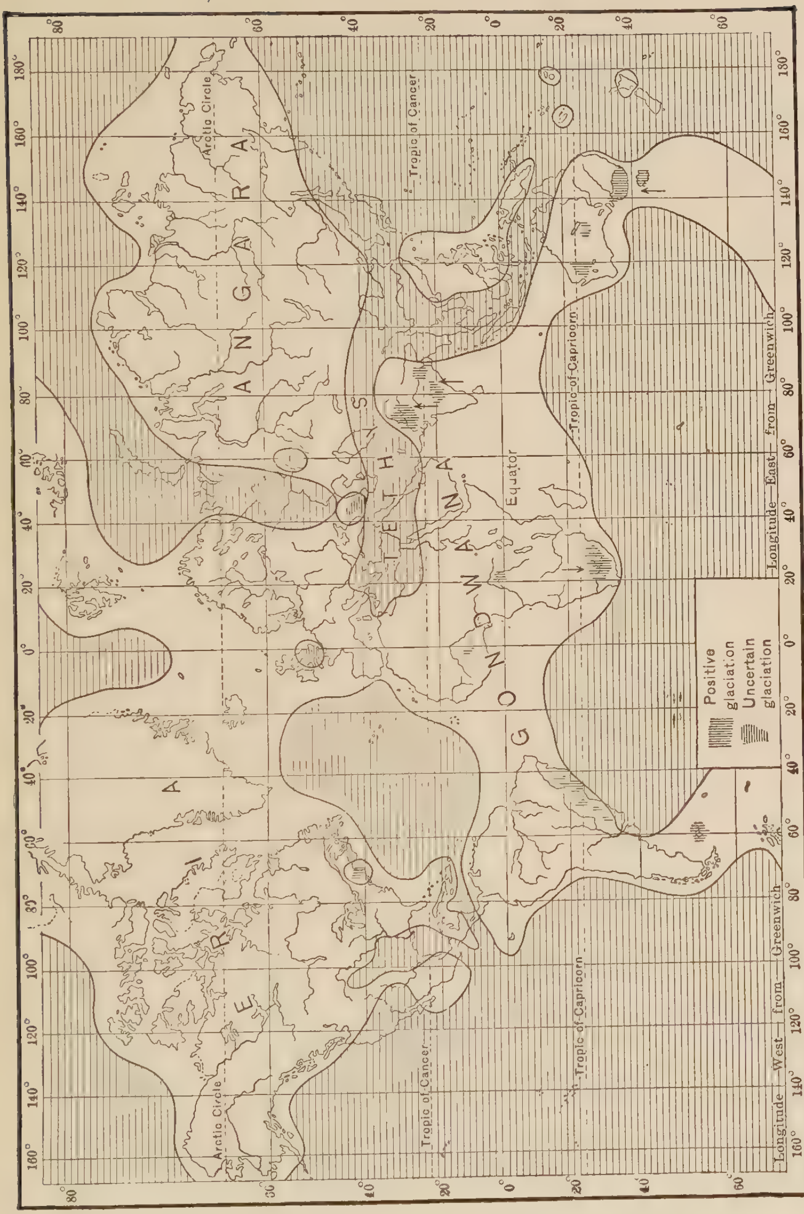


FIG. 148.—Map of the world in early Permian time showing a connection between all continents including Australia. (*From Shull, et al., Animal Biology, after Schuchert.*)

FIG. 149.—Map of the world in middle Cretaceous time showing the separation of continents. (*From Shull, et al., Animal Biology, after Schuchert.*)

network almost hopeless of disentanglement except in their broader aspects. Paleontology and Geology furnish the only evidence that can help in the solution of the problem.

The discontinuous distribution of animals in parts of the world separated by insurmountable barriers at the present time is no argument against evolution; on the other hand, evolution is the only reasonable explanation that has yet appeared. The peculiar fauna of Australia is undoubtedly due to the fact that that continent has been isolated from other continents since the beginning of *Cenozoic* times, with the result that the mammals native to Australia are comparable to those alive at the period immediately preceding the Cenozoic era. Presumably, therefore, these animals failed to survive in other parts of the world because of their inability to meet the competition of more favorably endowed forms. The result is that Australia, before the influx of civilized man, possessed a fauna of *Mesozoic* life, while the higher types of mammals were being evolved in other parts of the world.

Evolution in Man.—The evidence for evolution in man is similar to the evidence for the evolution of animals. The structure of the human body is that of a vertebrate, without doubt the most highly developed and intelligent vertebrate, but neither more nor less than a vertebrate. Man belongs to the Class *Mammalia*, Order *Primates*, Suborder *Anthropinae*, Genus *Homo*, of which there is but one living Species, *Sapiens*. Remains of ancient and extinct races of men show that they possessed ape-like skulls with prominent supraorbital processes, sloping foreheads, and protruding jaws. Similar features are noticed in modern primitive races. *Ape-like characters* crop out occasionally in men today, as, for example, in the ears being pointed above instead of rounded and by the presence of unusual quantities of hair about the ears and over the entire body. There is said to be a closer resemblance between the young of man and of adult apes than between the young of man and adult man. Thus, in the human infant the great toe stands out and the foot is almost prehensile; the abdomen protrudes; the arms are longer in proportion than the legs; the grip of the hand is so great that a three-weeks-old infant can grip a stick with sufficient strength to support its own weight.

Prehistoric Man. The ancestry of man has been traced back for a period of 400,000 years (Osborn). The *Java* or *Trinil*

man, found in Java, the most ancient human remains known, lived before the *Ice Age*, but even then had sufficient intelligence to build a fire and to make flint tools. Other prehistoric types

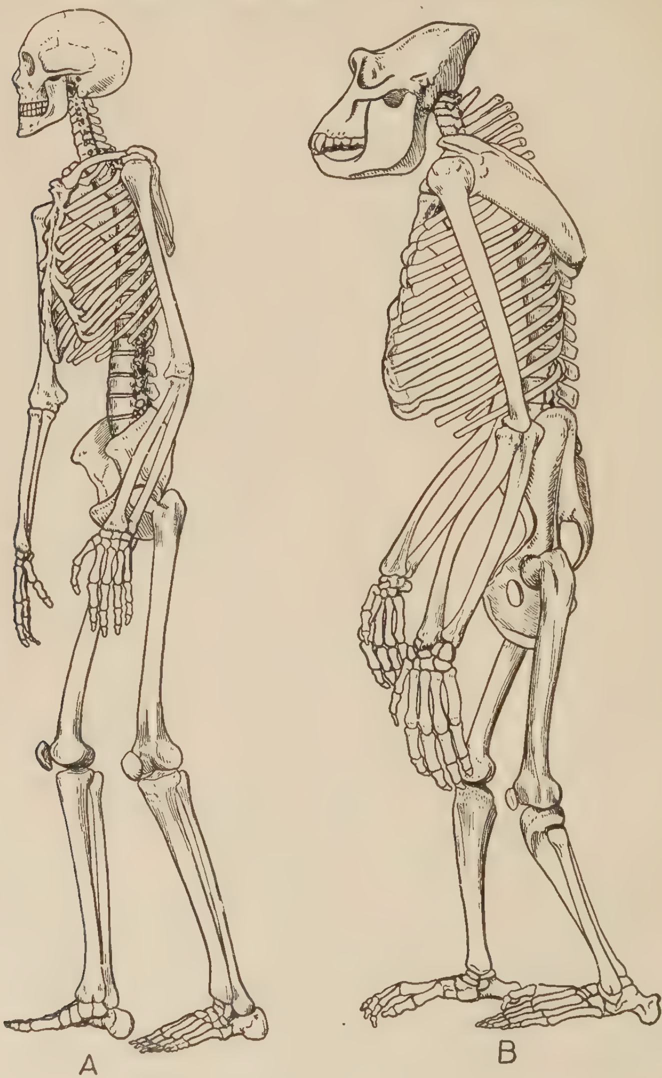


FIG. 150.—Skeletons of man and of gorilla. (*From Lull, Organic Evolution, copyright, The Macmillan Co. By permission.*)

are the *Piltdown man*, found near Ipswich, the *Heidelberg man* found on the Neckar River, Germany, the *Neanderthal man* from

quarries in Germany, and, finally the *Crô-Magnon man* from France and Wales. The latter lived 30,000 years ago and is probably our nearest and most direct prehistoric ancestor.

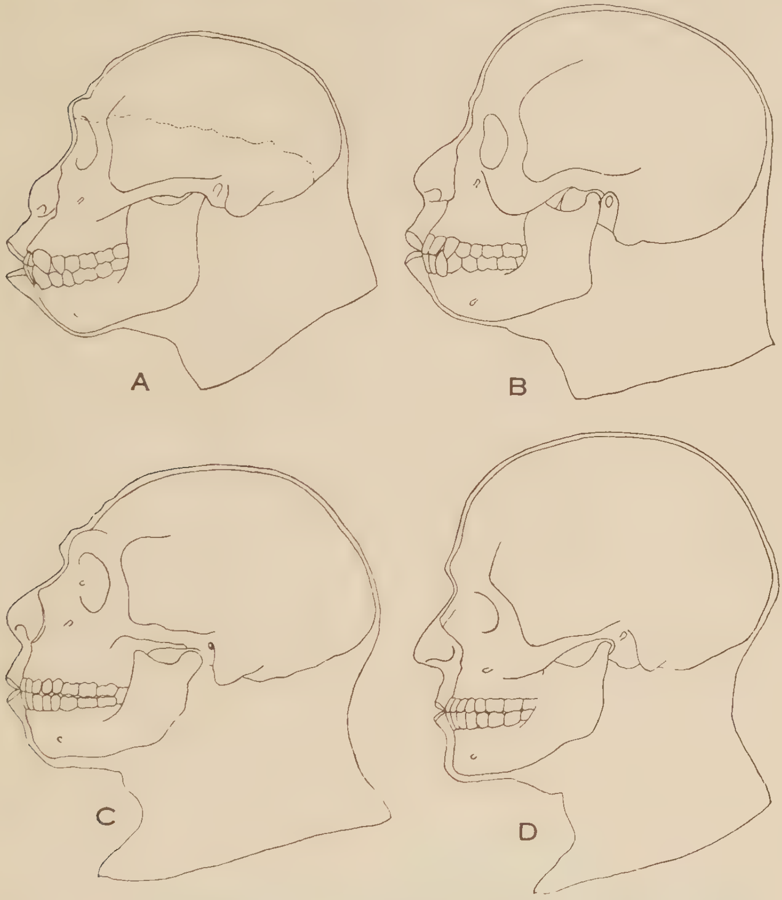


FIG. 151.—Prehistoric men. The types are not stages in a single evolutionary line, but probably represent divergent lines. A, Java man, *Pithecanthropus erectus*, lived approximately 500,000 years ago. Portion below irregular line restored. B, Piltdown man, *Eoanthropus dawsoni*, 200,000 to 300,000 years old. C, Neandertal man, *Homo neandertalensis*, 60,000 to 150,000 years old. D, Crô-Magnon man, *Homo sapiens*, 30,000 years old. (*After Lull, The Evolution of Man, Yale Univ. Press.*)

Man's Advance over other animals has been due to the exercise and development of cunning rather than physical strength, although the human body as a machine is probably the most efficient mechanism known. Man has been helped or, rather,

he has helped himself in his strides upward, by the use of tools and weapons, which considerably increased his defensive and offensive strength against enemies, and by developing the art of using shelter and storing food to an unprecedented degree. His prolonged and protected infancy has given opportunity for the organs, especially the nervous system, to develop a high degree of perfection. The gradual evolution of social life, the use of language, and the exercise of intelligence have all contributed toward raising him to a plane far above that of his fellow creatures and making him a dominant figure in the world. These later acquisitions have enabled him within certain limits to control his environment to a far greater extent than any other animal and to make him more or less independent of his surroundings.

Value of Evolution Doctrine.—The foregoing constitutes a very brief outline of the character of the evidence supporting evolution. None of it is experimentally demonstrable, because it has not yet been possible to change one species into another, to bring about experimentally the evolution of a lower form into a higher one. Biologists and many other people accept the principle of evolution as an explanation of the conditions of life past and present because it is the only *plausible interpretation* applicable to many facts of biology and contradicted by none. By scientists, evolution is accepted as a *general biological principle*—the debate goes on as to the *manner* in which it has been brought about.

References

Darwin, Charles: "Origin of Species," London, 1859.

Jordan, D. S. and Kellogg, V. L.: "Evolution and Animal Life," D. Appleton & Company, 1907.

Lull, R. S.: "Organic Evolution," The Macmillan Company, 1917.

Osborn, H. F.: "From the Greeks to Darwin," Columbia University Press, 1894.

Schuchert, Charles: "Historical Geology," John Wiiley & Sons, 1924.

Yale Sigma Xi Lectures, 1916–1919, "The Evolution of the Earth and its Inhabitants," Yale University Press, 1922.

Yale Sigma Xi Lectures, 1921–1922, "The Evolution of Man," Yale University Press, 1922.

CHAPTER XVII

THEORIES OF EVOLUTION

Evolution as an explanation of the origin and development of the earth and its inhabitants is not a new or modern idea, but one that has appeared in one form or another again and again in the history of philosophical biology. Man has always wondered as to how the earth was formed and the diversity of life produced; and he has always made some effort to find an answer. Some of the answers have been pure speculations distorted and biased by superstition and religious concepts, while others have been honest attempts to solve the riddle in terms of natural phenomena. *Naturalistic explanations* have always been more or less evolutionary in character, but until the time of Darwin no one had succeeded in constructing a theory that made a compelling appeal to students generally. The common misconception that *Darwinism* and evolution are the same is due to the fact that evolution became a topic of general discussion among people at large only after the publication of Darwin's books on the subject. In the popular mind evolution means Darwinism, whereas Darwinism is only *one* explanation of evolution. Evolution does not by any means stand or fall with Darwinism.

Lamarck.—The French biologist, Jean-Baptiste Lamarck (1744–1829), was one of those who, after spending a life time in serious application to the problem, attempted an evolutionary explanation of life. Lamarck did not formulate a complete theory of evolution, but since his conclusions were based on careful and painstaking observations they deserve more attention than they have received in the past. Lamarck's views may be briefly summarized as follows: (1) The environment has a *direct effect* in modifying organisms. (2) Organisms develop new structures and parts as the result of *need* (not that an animal can gain a new part by wishing for it, but that it does in some unknown way develop new parts as they are required). (3) *Use* or exercise develops an organ, while *disuse* results in atrophy. This is perfectly sound physiology based on everyday observa-

tion. (4) All characteristics however acquired are *inherited*, that is, all changes, whether caused by environment, habits, use or disuse, are inherited, thus accounting for the evolutionary changes that have brought about the perfection of adaptions by assuming the inheritance of all characteristics acquired by an organism during its life time.

Lamarck failed to win many supporters for his views during his lifetime, largely because of the general unpopularity of the subject of evolution, even in scientific circles. Then, too, his work did not always carry full conviction even to those sympathetically inclined. More serious attention has been given to Lamarck in later years largely because of renewed interest in the subject of the *inheritance of acquired characteristics* as a factor in evolution, the so-called *Lamarckian* factor. It might be noted that paleontologists in general have always strongly insisted upon the actuality of a Lamarckian factor in evolution because of the evidence of steady *progressive evolution* found in fossil series.

Darwin.—Charles Darwin (1809–1882), an Englishman, at the age of twenty-two was appointed Naturalist on H.M.S. *Beagle* which made a voyage around the world lasting five years. Darwin remained with the vessel three years, being compelled at the end of that time to return home on account of ill health. While he was with the expedition he collected quantities of biological material and compiled copious notes embodying accurate and critical observations. After more than twenty years spent in labor over his material, supplemented by numerous experiments carried on at his country home, he published the results of his work in a series of books, the first of which, the "*Origin of Species*" appeared in 1859. The year before, Darwin had received a note from his friend, Alfred Russel Wallace, also a naturalist, then in the Malay Archipelago, in which the latter communicated an explanation of evolution identical with Darwin's. Darwin in a spirit of great magnanimity favored withholding his own conclusions and allowing Wallace alone to receive full credit for the theory, but he finally yielded to the persuasions of mutual friends and a joint communication outlining the theory was read before the Linnæan Society in London.

Natural Selection.—Darwin says that the argument for his theory was suggested by reading in 1838 an article by Thomas Malthus on the Law of Population, to the effect that:

1. Man multiplies in a *geometrical* ratio.

2. The food supply is relatively *constant* from year to year.

3. Therefore the world would soon be *overstocked* were not population checked by wars, famine, vice, misery, etc. This gave Darwin the germ of an idea which he elaborated in his theory of evolution by *Natural Selection* as follows:

1. Living things reproduce in *geometrical* ratio.

2. The food supply from year to year is relatively *constant.*

3. Hence, there is a *struggle for existence,* for food.

4. Animals vary and *variations are inherited.*

5. As a result of propositions 3 and 4, the *fittest animals* in each generation *survive.*

6. Environment changes, and in meeting these changes there is a *natural selection* of the fittest animals, which gradually brings about changes in the species.

Darwin's theory made tremendous appeal because he based his conclusions on facts to a far greater extent than any of his predecessors. Thus, in support of his first point on the rate of reproduction the following may be mentioned: The female *salmon* at the age of four years leaves the sea, ascends a river, lays some 4,000 eggs and then dies. If every salmon egg were to develop to maturity, at the end of fifty years there would be sixteen followed by forty-two ciphers of salmon, a number so large that there would be scarcely room in all the waters of the sea to contain them. Even the slow-breeding *elephant,* which, beginning at thirty years of age and ending at ninety, brings forth six young on the average, would at the end of 800 years provide 19,000,000 descendants. In *man,* were breeding to continue unchecked for, say, 1,000 years, there would be hardly standing room on the earth. (Jordan and Kellogg.)

There is no question but that animals reproduce in a geometrical ratio, but it is also true that the total numbers from year to year are practically constant. The limiting factor in controlling numbers is the *food supply,* which fixes the number of animals that can be supported in any given area. Since more animals are produced than can possibly be fed, there results a *struggle for existence,* which is largely a struggle for food.

Variation.—It is also a fact many times confirmed that offspring of the same parents *vary* in size, strength, vigor, etc., and Darwin assumed that these variations, favorable or otherwise, are *heritable.* The struggle for existence, therefore, would

be modified by the facts of variability and heredity, with the result that the *fittest* are selected to survive entirely through the operation of natural conditions. The character of the survival would also be influenced by changing environmental conditions. Thus the food supply of a large area, while averaging constant from year to year, often shows local fluctuations which compel animals to migrate from famine zones to regions of plenty. The immigration of a foreign species introduces a *competitive factor* for the native stock that might in extreme cases result in their extermination, unless necessary readjustments were perfected to meet the invaders in the proper manner. *Geographic changes* such as are known to have occurred in the past must, in all probability, have been potent factors in modifying the struggle for existence. Thus, when islands are formed by separation from the main land the problem of living becomes an entirely different one for those cut off on the island, and if they survive, the chances are that in the course of time they will develop distinctive characteristics. Similarly, changes of consequence to the inhabitants occur when a continent is cut in two by an isthmus, or when two continents become joined. The formation of a mountain range by volcanic eruption results in a barrier as effective as water for many animals and may bring in its wake climatic differences on the two sides of the barrier that also change living conditions and eventually bring about changes in the inhabitants. When new conditions of life arise, animals must meet them or perish. Granted that the *proper variations* materialize at the *proper time* to enable living things to overcome new obstacles, the fittest of each generation will in the course of time come to differ so much from the original stock as to be a distinct species. Evolution results from the survival of the fittest.

It will be noted that there are two fundamental assumptions in Darwin's theory: *first*, that the proper or *necessary variations* appear at the right time; and, *second*, that these variations are *heritable*. Darwin offered no explanation for variability—variation is axiomatic, since no two animals are ever identical, except identical twins, for which there is a special reason. He did, however, make a distinction between two kinds of variations, one of which is called *fortuitious* or *fluctuating* and the other *sport* variation. The difference between them may be illustrated by measuring the individual heights of, say, 1,000 college men,

grouping the heights into *classes,* and making a *graph* by plotting the frequency of height classes on the *ordinate* and the value of

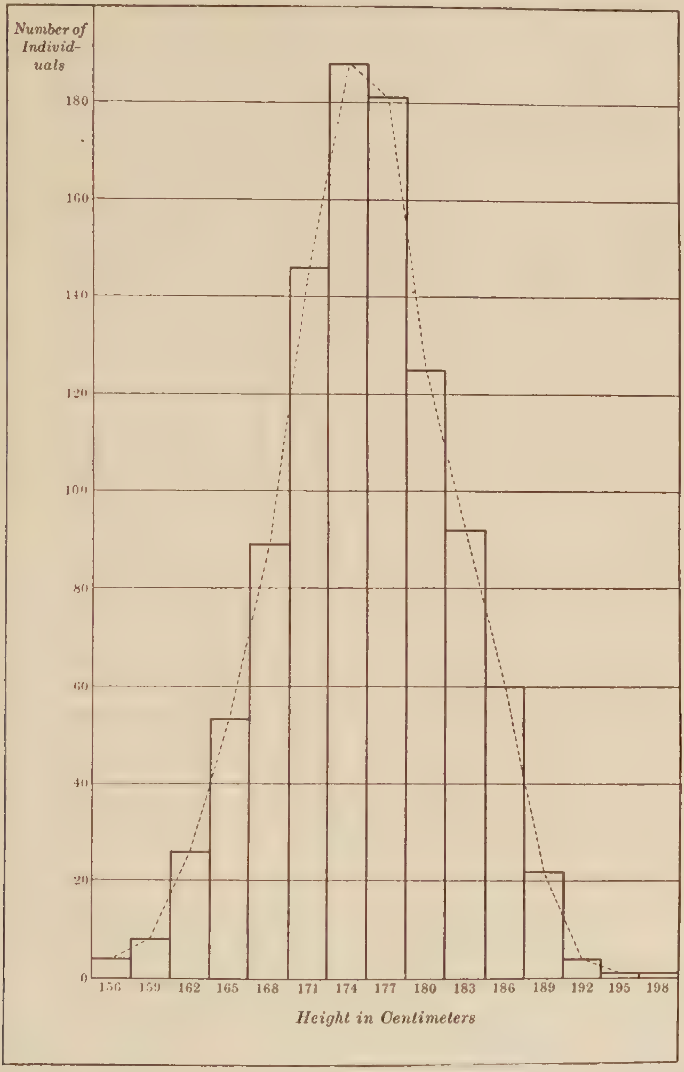


FIG. 152.—Frequency polygon and curve showing variation in height of 1,000 college students of ages 18 to 25. Modal class 174 cm.; average height 174.4 cm. (*From Castle, Genetics and Eugenics, Harvard Univ. Press. By permision.)*

the classes on the *abscissa.* Height classes are formed of 3 centimeters each so that students measuring 155, 156, or 157

centimeters are placed in a common class, the mean value is 156 centimeters. The class containing the largest number of individual is known as the *mode,* from either side of which the classes fall off to the extremes. The graph illustrates the distribution of fluctuating variations. The *average height,* 174.4 centimeters, is somewhat greater than the modal height, because there are more individuals taller than the mode than there are shorter. (Castle.)

Now, suppose that there had been one or two individuals in this group measuring 210 centimeters in height. If plotted, their position would be outside the limits of the range for the majority of the group to which they would not be related or connected by intermediate groups. They would illustrate *Darwin's* idea of sport variation.

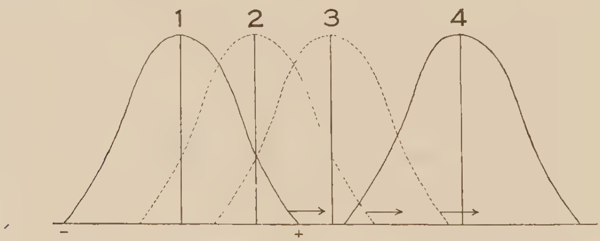


FIG. 153.—The hypothetical effect of selection on a single character.

Origin of Species.—Darwin attached more importance to fluctuating variations because he believed sports occurred too rarely in nature for Natural Selection to act upon them. Fluctuating variations, on the other hand, are *invariably* present to meet the demands of environment. To illustrate how fluctuating variations supply the groundwork for evolutionary changes, suppose that *plus* variations, *i.e.,* variations greater than the mode, of any given sort represent desirable qualities, that improve the equipment of the owner in the struggle for existence. As a result of the struggle for existence, *minus* variants would tend to be reproduced in smaller numbers, so that the mode in succeeding generations would shift in a *plus* direction. Through the gradual elimination of the minus individuals in each generation, the variation polygon 1, representing the original distribution of the character, would shift in a plus direction to position 2, then to 3, and finally to 4, which represents an entirely new range variation, completely separated from 1 (Fig. 153).

Now if the same argument is applied to other variable parts of the animal, there would result in later generations an entirely different sort of animal from the original one. The gradual accumulation of slight variations brings about the development of *a new species.*

On the other hand, *sport* variations would hasten the process, since a sport represents a larger change from the mode than any fluctuating variation. Darwin understood this, of course, but he failed to attach much weight to sports in this connection, because, as has been said before, he believed they occurred too *infrequently* to be of any real value in the struggle for existence.

Darwin, like Lamarck, assumed that *all* variations are inherited, which simplified his explanation of the action of Natural Selection. It is now known that fluctuating variations are not inherited and, while this fact does not destroy Darwin's theory, it, in effect, reduces the principle of Natural Selection to the rôle of an *eliminating agent* rather than a *creative factor* in evolution—it determines whether or not a character shall survive *after* it has appeared. The work of de Vries and Johannsen has been important in establishing this point of view.

The Mutation Theory.—In 1886 Hugo de Vries, a Dutch botanist, found a number of evening primroses, *Œnothera Lamarckiana*, growing wild in an abandoned potato patch at Hilversam, Holland. The interesting feature about these plants was that, in addition to the usual fluctuating variants, he found a number of sports or *mutations*, as he called them. On transplanting some of the typical *Lamarckiana* to a garden where he could keep them under observation, he found that in the course of seven generations, out of some 50,000 plants produced, that six or seven different mutations, totaling 800 plants, were produced from the parent stock. Since the new variations were inherited, de Vries naturally inclined to the view that mutation must be a very important factor in evolution.

Mutations according to de Vries, are due to changes of unknown cause in the *germplasm*, the hereditary substance of the germ cells, while fluctuating or Darwinian variations are due to variations in the *somatic* or body cells which are not heritable. For this reason de Vries discredits Darwin's idea of a gradual accumulation of fluctuating variations, under the guidance of Natural Selection, as a factor in evolution.

TABLE 3.—AN EIGHT-GENERATION PEDIGREE CULTURE OF LAMARCK'S EVENING PRIMROSE

Generation	Gigas	Albida	Oblonga	Rubrinervis	Lamarckiana	Nanella	Lata	Scintillans
1	..	..	...	..	9			
2	..	..	...	..	15,000	5	5	
3	..	..	...	1	10,000	3	3	
4	1	15	176	8	14,000	60	73	1
5	..	25	135	20	8,000	49	142	6
6	..	11	29	3	1,800	9	5	1
7	..	..	9	..	3,000	11		
8	..	5	1	..	1,700	21	1	

The giant mutant was obtained only once, but all the others, in at least three different generations, from Lamarckiana parents. (*From Castle: "Genetics and Eugenics," Harvard University Press.*)

De Vries's work gave great impetus to the study of mutations in animals as well as in plants. The sports of Darwin correspond in every way to mutations, and they have been observed in all animals though not in great abundance. *Black sheep*, in an otherwise white flock, *albinos*, individuals lacking pigment in the skin, hair, and eyes, *hornless cattle*, *mule-footed pigs*, toes enclosed in a solid hoof, *six-fingered hands* and *six-toed feet in men* are common examples of mutation. It has also been established that all of these conditions are hereditary, which indicates that they have their origin in the *germplasm* rather than in the *soma*. On the other hand, there is some question as to whether mutations as they occur in Œnothera really possess the significance attached to them by De Vries. To take the case of the Œnothera mutants, which really form the basis of his theory, there is not entire agreement as to their *origin*. According to certain investigators, *Lamarckiana* is not a *pure* stock, but some sort of complex *hybrid* whose mongrel character is exhibited by the production of variants from time to time. However, it is also true that mutation in other organisms is not due to hybrid parentage, but rather to some inexplicable change in the germplasm which results in a sport; but, as will be seen later, the nature of the mutation in many cases is such as to make them of doubtful value in species formation, because of their abnormal character. It is, of course, possible that mutations may sometimes be in practical directions. So far as Darwin's theory is concerned, the occurrence of mutations would merely *hasten* the process of evolution, for the simple reason that changes would occur

quickly instead of by the slow accumulative method. In other words, if one were to substitute *germinal variation* for *fluctuating variation* the argument of Darwin's theory might still hold.

Pure Lines.—The work of the Danish botanist Johannsen had a very important bearing on the theory of the *limitations* of selection. Johannsen found that when the progeny of a single

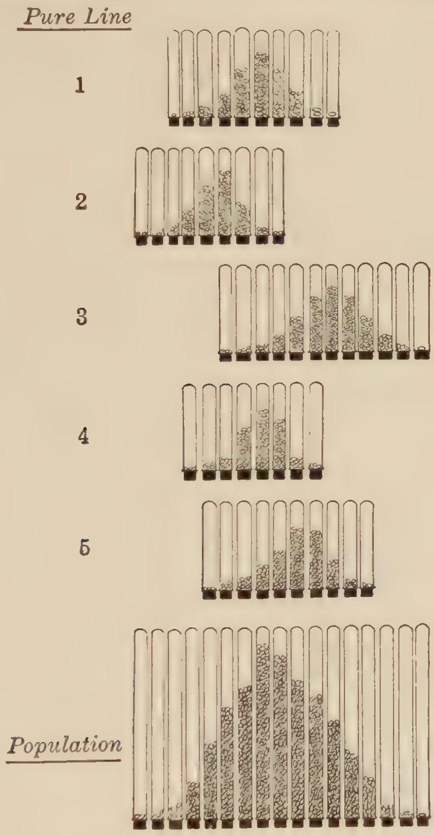


FIG. 154.—Diagram to illustrate five pure lines derived from a population of beans assorted according to weight. Tubes containing beans of the same weight are placed in the same vertical row. (*From Walter, Genetics, copyright, The Macmillan Co., after Johannsen. By permission.*)

bean of a common garden variety were separated from the rest it was possible to isolate *pure lines*, which differed in average weight. By selection he was able to break up the bean population into a number of such pure lines, but selection *within* the pure line failed to shift the mode of the variation curve in either a plus

or a minus direction. The only result of selection, then, was the isolation of pure lines, that is, groups with similar germinal constitution. Selection failed to *create* new forms.

Johannsen concluded, therefore, that the general population of beans, showing variation in weight in much the same way as a population of men shows a variation in weight, is really made up of a number of pure *weight lines.* The difference between pure lines rests upon an hereditary basis, the variation *within* the pure line upon non-heritable factors. Within a pure line some beans are larger or smaller than the average because of slight environmental differences, and for that reason selection within the pure line fails to shift the mode.

Were the pure-line hypothesis as outlined to represent a general condition, then selection could have no power in creating new species—it could only *isolate* pure lines. The only conceivable way (at the present time at least) in which a change could occur in a pure line would be by mutation; all of which tends to emphasize the importance of the mutation theory. It remains, however, to be seen whether selection is always impotent within pure lines when other characters generally are considered. There is reason to believe from the work of Jennings on the protozoan, *Difflugia,* that the selection may be effective to a certain extent within the pure line.

So much for a bare outline of some of the theories and experimental work that has had really a permanent value along evolutionary lines. More extended accounts should be read from the literature listed below.

References

LAMARCK, J. P.: "Zoological Philosophy," Translation by Hugh Elliott, The Macmillan Company, 1913.

JORDAN, D. S. AND KELLOGG, V. L.: "Evolution and Animal", Life. D. Appleton & Co., 1907.

KELLOGG, V. L.: "Darwinism Today," H. Holt & Company, 1907.

SCOTT, W. B.: "The Theory of Evolution," The Macmillan Company, 1911.

DE VRIES, HUGO: "Species and Varieties," Open Court Publishing Company, 1905.

WALTER, H. E.: "Genetics," The Macmillan Company, 1922.

CHAPTER XVIII

HEREDITY

Darwin endeavored to explain heredity by assuming that *gemmules*, hypothetical microscopic bodies of some sort, are emitted by the somatic cells and carried by the circulatory fluids to the germ cells, where they are stored; as a result of which, the germ cells are enabled to reproduce in the offspring characteristics acquired by the parent somatic cells. In other words, through the agency of the gemmules the germ cells become a depository where changes undergone by body cells are recorded in such a way that the germ cells are capable of reproducing these changes in body cells of the next generation. This explanation was not found on actual observation but was proposed by Darwin in a tentative way to show how characters acquired during the life time of an individual might be inherited by his children—a vital point in the theory of evolution by Natural Selection. The *gemmule hypothesis* is mentioned merely for the sake of its historical importance, for no one has succeeded in finding any evidence to support it. Experiments designed to test the points at issue have so far failed to demonstrate conclusively that changes in somatic cells can effect an impression on the germ cells in such a way as to enable the latter to reproduce similar somatic changes in the next generation.

Chromosome Theory of Heredity.—The generally accepted explanation of the hereditary mechanism today rests on the efforts of a large number of workers, of whom the most important in this particular connection are O. Hertwig, Strassburger, and Weismann, whose researches laid the foundation for the conclusion that the *chromosomes* are the bearers of hereditary qualities. This belief is based upon the following general argument:

Since the egg is a relatively *large* cell and the spermatozoön a *small* one, the only substance contributed in *equal* amounts by the parents in fertilization is the *chromatin* of the egg nucleus and the *chromatin* of the male nucleus, the latter derived from the head of the sperm; since, in the long run, offspring *inherit*

equally from the parents, it follows that the *chromosomes* must be the bearers of the hereditary qualities.

Germplasm and Somaplasm.—To Weismann, more than any other, belongs the credit for the elaboration of this idea and for stimulating a host of biologists to intensive study of the problem. Weismann was the first to draw a sharp distinction between *germplasm* and *somaplasm.* Germplasm is the hereditary material and is located in the nucleus of the germ cell, while somaplasm is nutritive and vegetative in function. Germ cells and somatic cells are both derived from the fertilized egg, but the germ cells, derived by direct cell lineage, retain the reproductive potentiality of the egg, while the somatic cells lose the power to reproduce when they differentiate into body cells.

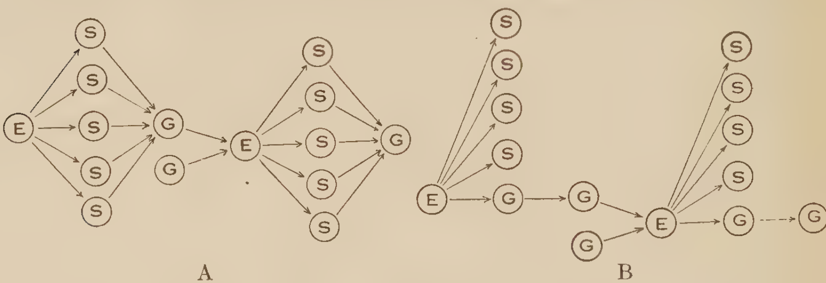


FIG. 155.—A, diagram to illustrate Darwin's idea of gemmules. B, diagram to illustrate Weismann's germ-track. E, fertilized egg; G, germ cell; S, soma.

As a result, there is a continuous line of germ plasm, a *germ track*, extending from one generation to the next; since germ cells only come from germ cells. On the other hand, the generation of somatic cells in any given case terminates with the death of the individual. Weismann further assumed that the chromosomes have a very definite and complex organization, which, however, need not be considered here.

According to Weismann, during cleavage and differentiation, the chromosomes undergo a *differential distribution*, upon which the differentiation of somatic cells depends. Something of this sort is indicated in the early cleavage of the nematode worm, *Ascaris*, but, since a similar chromosome behavior does not occur in other eggs generally, the evidence for a visible differential distribution or division of chromosomes during cleavage is unsatisfactory.

Granted that the chromosomes represent the material basis of heredity, one can understand the significance of the reduction

divisions in gametogenesis; for without such reductions there would be a doubling of chromosomes and therefore, of hereditary qualities at each reproductive period. The *biparental* character of the chromosome complex of the egg accounts for the biparental character of inheritance, which is, of course, in keeping with the reduction phenomena.

FIG. 156.—Differentiation of germ cells and somatic cells in the egg of *Ascaris*. A and B, second cleavage division showing that the chromosomes remain entire in the lower cell, which is in the line of descent of the sex cells (germ track), but that they throw off their ends and break up into small granules in the upper cells which become somatic cells. C, 4-cell stage, the nuclei in the upper (somatic) cells being small and the ends of the chromosomes remaining as chromatic masses in the cell body outside of the nuclei, while the nuclei of the lower cells are much larger and contain all the chromatin. D, third nuclear division, showing the somatic differentiation of the chromosomes in all the cells except the lower right one, which alone is in the germ track and will ultimately give rise to sex cells. *(From Conklin, Heredity and Environment, Princeton Univ. Press, after Boveri. By permission.)*

Cytoplasm in Heredity.—Weismann ignored the cytoplasm of the cell as an element in heredity, but there has been a growing tendency toward a much broader viewpoint. Thus, it has been

shown by Conklin and others that the *polarity* of the embryo and the adult is established in the *cytoplasm* of the egg *before*

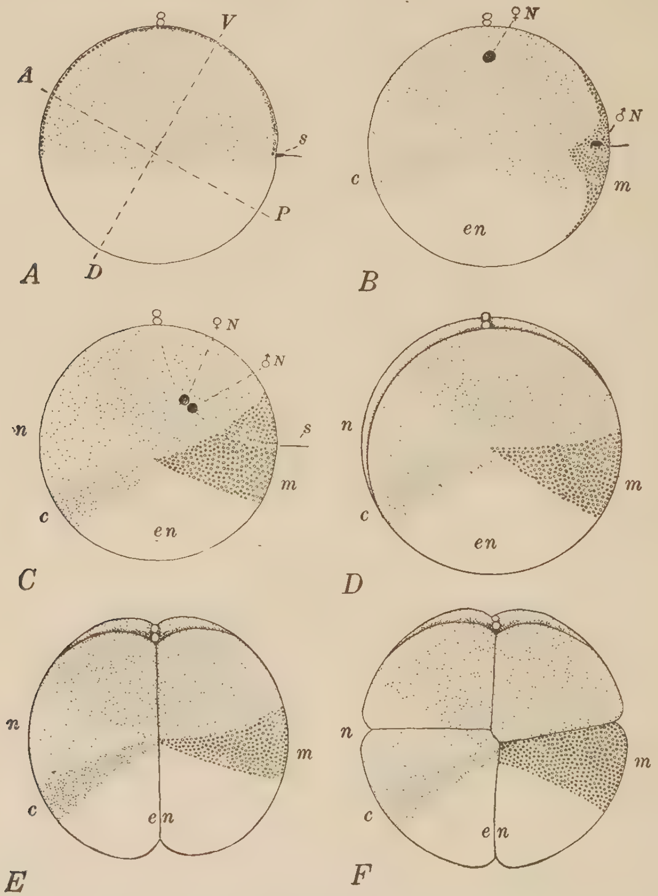


FIG. 157.—Diagrams of frog's egg showing the probable relations of the axes of the egg to the axes and principal organs of the embryo. All eggs viewed from the right side, polar bodies above. A, anterior; P, posterior; D, dorsal; V, ventral; *s*, spermatozoön; ♂N, sperm nucleus; ♀N, egg nucleus; *m*, mesodermal crescent, where mesoderm will form; *c* and *n*, gray crescent, where chorda (*c*) and nervous system (*n*) will form; *en*, area of endoderm, pigmented area around polar bodies will form ectoderm of skin. A, before entrance of spermatozoön. B, just after entrance to sperm. C, union of egg and sperm nuclei. D, 2-cell stage. E, 4-cell stage. F, 8-cell stage. (*From Conklin, Heredity and Environment, Princeton Univ. Press.*)

fertilization. In many eggs, *areas* can be distinguished, the materials of which are later distributed to particular regions of

the embryo. The substances composing these areas are known as *organ-forming substances*, of which three kinds, *ectoplasmic*, *endoplasmic*, and *mesoplasmic*, can usually be distinguished. The cytoplasm of the unfertilized egg, therefore, possesses a considerable amount of organization or *preformation*, which must be taken into account in any consideration of the material basis of heredity. While it must be admitted that there is much evidence for the view that the chromosomes constitute a very important part of the hereditary mechanism, there is also every reason for believing that the cytoplasm is concerned too, especially with the factors which determine the *groundwork* of development. The facts at hand justify the conclusion that there is in the egg a specific and highly organized *initial plasma*, which, with the *chromosomes*, composes the inherited material basis of development. *Embryogenesis* may be looked upon as a series of progressive stages, each stage a preparation for the next, motivated by the interaction between *inherited* internal factors, located in the *nucleus* and *cytoplasm* of the germ cells (preformation), and *non-inherited* external factors supplied by the *environment* (epigenesis).

Inheritance of Acquired Characters. –From the Weismannian point of view, peculiarities acquired by the body cells through special training and experience cannot be inherited because the effects of such changes in the soma do not act upon the germplasm in a *specific* manner. One difficulty in dealing with this question exhaustively in a brief space is that the term *acquired characters* includes a large category of conditions which are not at all homogeneous. Everyone knows that if a man loses his legs as the result of an accident that his children are not born legless. If the effects of bodily injuries were inherited, we would be a race of cripples. It goes without saying, therefore, that *mutilations* are not heritable; neither is there any ground for the popular belief that *maternal impressions* produce specific effects upon unborn young. Experimentally, it has been found very difficult, if not impossible, to alter the soma in such a way as to produce an inherited defect; all of which, of course, supports Weismann. On the other hand, had no characters been acquired by primitive protoplasm, there would have been no evolution; and we say glibly enough that the fully developed individual is a product of "*inherited nature*" modified in one way or another by "*non-*

inherited nurture," which implies a very definite rôle for *environmental* factors in development.

The crux of the whole matter seems to be that experiments so far devised to test the alterability of the hereditary basis have been too crude, largely because of ignorance of detailed knowledge of the chemistry and physics of protoplasm. The experimenter either applies too much pressure on the organism and kills it; or else not enough. The happy medium remains to be found. In the mean time, the body of evidence points to the *non-inheritance of acquired characters*, if by an acquired character is meant a modification or a variation in the soma resulting from a purely environmental cause.

Direct Action of External Factors on Germplasm.—Stockard and Papanicolaou have succeeded in producing eye defects and deformed limb skeletons in the offspring of guinea pig parents which had been subjected to the inhalation of alcohol fumes, and the defects were inherited in succeeding generations without further treatment with alcohol. The original, treated parents showed no ill effects from the alcohol, so that the effect in the progeny must be explained by assuming that the germplasm of the parents had been injured to the extent of producing a permanent change. In other words, the disturbing factor, alcohol, acted directly upon the germ cells, and not through the intermediary of the soma. The experiment, therefore, does not demonstrate the inheritance of acquired characters.

Parallel Induction.—Guyer and Smith injected into the blood stream of fowls the pulped lenses of rabbit eyes, securing thereby an *antilens* substance in the fowl's blood. When such antilens serum from the fowl was injected into the blood vessels of pregnant rabbits, the offspring showed a number of eye defects, of which the most common were opaque lenses, small eyes, and abnormally rotated eyes. These defects were inherited in succeeding generations through both male and female lines. Guyer and Smith regard the result as due to the simultaneous effect of the antilens serum on the germinal factors and the somatic tissues of the same individual, an effect sometimes called *parallel induction.* Little and Bragg have also produced eye defects in young mice by exposing pregnant mothers to X-rays. The defects in this case were also inherited.

It is highly interesting and undoubtedly as significant that the same parts, namely, the eyes, and, to a certain extent, the brain,

were affected by a variety of harmful agents. Thus, in all cases the head end of the animal showed the primary defects, which, in view of the fact that the work of C. M. Child has demonstrated that the head end of an embryo is the region most susceptible to the action of harmful agents, suggests that the results obtained were due rather to a general effect of a disturbing agent on the most susceptible part of the body. Alcohol, antilens serum, and X-rays all seem to produce similar results so far as the eye is concerned, so that the idea of *specificity of action*, as, for example, in the effect of the antilens serum, is rather difficult to maintain. The skeleton defects noted especially by Stockard and Papanicolaou may well be secondary results following the primary injury to the region of highest metabolism, the head end of the body.

Germ Track.—The idea of a germ track, a *lineage* of germ cells more or less distinct from somatic cells, has played an important part in shaping opinion regarding the question of the inheritance of acquired characters. The evidence from embryology shows that germ cells arise very early in ontogenesis in many animals, from which the inference is drawn that somatic cells have very little to do with their differentiation beyond supplying conditions necessary for nourishment. The difficulty of understanding how changes in the soma could be transmitted to the germ cells in such a manner as to enable the latter to reproduce them in the soma of the next generation has been an *a priori* reason for questioning the possibility of the inheritance of acquired characters. At the same time the failure to demonstrate a germ track in all animals, notably in *cœlenterates* according to Hargitt and in *flatworms* according to Child, has done very little to alter this opinion because the evidence from experimental attempts to modify the germ cells by modifying the somatic cells in various ways has tended to support rather than refute the deeply rooted conviction that acquired characters are not inherited.

Mendelism.—In 1868, Gregor Mendel, an Augustinian monk, published the results of experiments which he had conducted upon the common garden pea, *Pisum sativum*, in the garden of the monastery at Brunn, Austria. His results remained practically unnoticed until 1900, when similar conclusions were reached independently by three men, de Vries, Correns, and Tschermak. For this reason Mendel's work does not begin to figure in evolutionary literature until about 1900. Mendel's

discoveries are important because he demonstrated by experimental methods the existence of fundamental *laws* governing the distribution of hereditary characters in offspring. These laws can be best understood by reviewing some of his experiments.

Law of Segregation.—On crossing a plant belonging to a race having *yellow* peas with one having *green* peas, Mendel found that the *hybrid*, or first filial generation (F_1) had *yellow* seeds. The next generation (F_2) produced from the F_1 gave *three* yellows to *one* green. The green when inbred gave only green from this point on. Of the yellows, one-third proved to be pure yellow, like the green, while the remainder behaved just like the F_1, producing *three* yellow to *one* green. In this experiment yellow is said to be *dominant* to green which is *recessive.*

Purity of Gametes.—The explanation of this result rests upon the assumption that the gametes are *pure* with regard to the *genes* or *factors* responsible for producing yellow and green in the seeds. That is, a gamete carries either yellow or green genes but never both. When, in the first part of the experiment, yellow and green genes were brought together to form the *zygote*, fertilized egg, of the F_1, yellow dominates green. In the formation of the gametes of F_1 the genes for yellow and green are *segregated* in different germ cells, with the result that the F_2 generation is composed of one pure or *homozygous* yellow, two mixed or *heterozygous* yellow, and one pure or *homozygous* green. Such a result is what would be expected on a basis of chance combinations between a male and female series of yellow and green gametes. A pair of characters like yellow and green behaving in this way are known as *allellomorphs.*

	Parents		Gametes		F_1 Zygotes		F_1 Gametes		F_2 Zygotes
Yellow	YY	⟶	Y Y		Yy	⟶	Y y		
				=				=	YY : 2Yy : yy
Green	yy	⟶	y y		Yy	⟶	Y y		

Law of Independent Assortment.—If a pea which is both *yellow* in color and *smooth* in contour is crossed with one which is *green* and *wrinkled*, the F_1 is yellow and smooth. Yellow is dominant to green, as before, and smooth is dominant to wrinkled. Inbred, the F_2 consists of nine *yellow smooth*, three *green smooth*, three *yellow wrinkled*, and one *green wrinkled*. All the yellows taken together are to the greens as 3 : 1; all the smooths taken together are to the wrinkled as 3:1; but some of the yellows are

now wrinkled and some of the greens are now smooth. In other words, while the results for each pair of characters are in accord with the *law of segregation*, a recombination of characters has taken place in accordance with what is called the *law of independent assortment* of different allellomorphs. Again, this result can be explained by assuming that gametes never carry genes for more than one member of a pair of allellomorphs.

The composition of the F_2 in this experiment can be shown more clearly if one arranges the F_1 gametes in a horizontal and

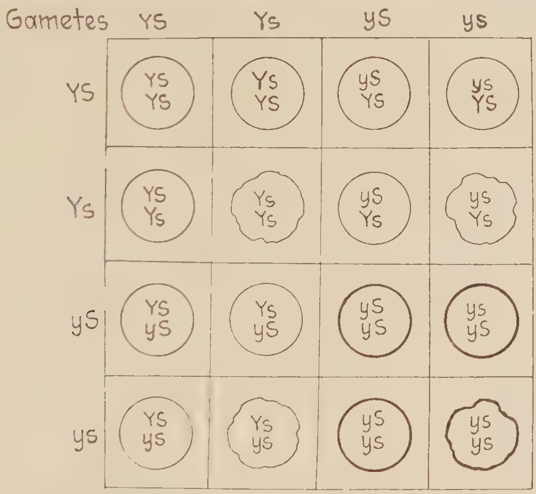
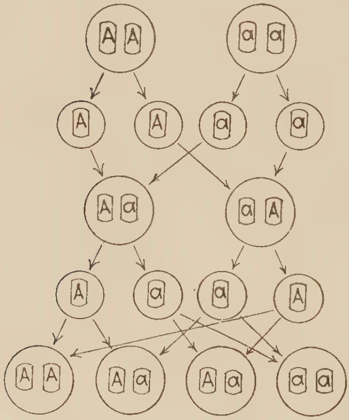


FIG. 158.—Diagram showing composition of the F_2 in a dihybrid cross. The light circles represent yellow smooth peas; the heavy circles green smooth; the light irregular circles yellow wrinkled; the heavy irregular circles green wrinkled. YSYS (yellow smooth) is an extracted dominant; ysys (green wrinkled) an extracted recessive; these with YsYs and ySyS are homozygous; the remainder are heterozygous. Summary: 9 yellow-smooth; 3 yellow wrinkled; 3 green smooth; 1 green wrinkled.

vertical series along two sides of a square and records the F_2 zygotes at points within the square where imaginary lines drawn from any pair of gametes intersect at right angles.

Unit Characters. A knowledge of the principles of segregation and independent assortment for the purpose of making whatever combinations one chooses not only has a great practical application but a greater theoretical importance, in that it shows that the individual is a complex of *unit characters* and that the genes or germinal representatives of these characters are carried in the *gametes*. In Mendel's time nothing was known about chromosomes but it has been pointed out since that the behavior of the

chromosomes in maturation supplies just the sort of mechanism that is required to explain Mendelian Inheritance, because the separation of members of homologous pairs of chromosomes in the reduction division of gametogenesis corresponds exactly with the separation of members of pairs of allellomorphs and their segregation in different gametes. Therefore, if one assumes that the genes are located in the chromosomes and that a chromosome never carries more than one member of a pair of allellomorphic genes, the manner of distribution of the chromosomes in maturation meets all the conditions required to explain the distribution of characters in Mendelian crosses.



Homozygous parents

Reduction division (only one class of gametes from each parent)

F_1 zygotes (all alike)

Reduction division (two classes of gametes from each F_1 zygote)

F_2 zygotes (1 homozygous dominant: 2 heterozygous: 1 homozygous recessive)

FIG. 159.—The behavior of a single pair of chromosomes in a Mendelian cross. Only the reduction division of maturation is shown. A, dominant; a, recessive.

Dominance.—In Mendel's experiments one of the characters of a pair is dominant to the other, but this is not always the case, and the question as to whether one character or the other is recessive is a matter of no theoretical importance for the principle of segregation. Often the F_1 characters show a condition *intermediate* between the parental characters, and sometimes an entirely *new* character is produced. Correns showed that when the Four-o-clock, *Mirabilis jalapa*, of the white variety is crossed with the red variety, the F_1 is pink, which is obviously a *blend*. Inbred, the result is 1 white: 2 pink: 1 red; the modification of the 3:1 ratio being due to the fact that the heterozygotes are pink.

As another example of *incomplete dominance*, if a black *Anadalusian* fowl is crossed with a white-splashed-with-black, the F_1 is slaty-blue. Inbred, these give for the F_2 1 black: 2 blue: 1 white-splashed-with-black.

When three pairs of characters are dealt with in hybridization, there are 64 possible combinations in the F_1 in the proportion of 27:9:9:9:3:3:3:1. Such experiments were actually carried out by Mendel, and others have since been conducted, indicating that the principle of segregation and independent assortment probably holds good for an indefinite number of characters.

Eye Color.—It has been found that Mendelian inheritance exists in all animals and plants. A common Mendelian character in man is *eye color*. Eye color is due to the amount and distribution of pigment in the *iris*. Dark-brown and black eyes have pigment present in the *outer surface*, through the *stroma*, and in the *inner surface* of the iris; light-brown, gray, and green eyes have less pigment in the outer surface; while blue eyes have pigment only in the inner surface of the iris. Brown is dominant to blue, so that when homozygous brown is crossed to blue the offspring are heterozygous brown; heterozygous brown mated with heterozygous brown gives 3 brown: 1 blue. Of the three browns, one is homozygous and the other two heterozygous.

Practical Application.—As might be expected, the principle of dominance has some practical importance in animal and plant breeding. Thus, the hornless or *polled* condition in cattle is a desirable character, because such cattle are easier to handle than horned stock. It happens that the polled condition is dominant to horned, so all that is necessary to insure production of hornless calves is the use of a pure homozygous polled male for breeding.

Sex Inheritance.—In Chap. XIV it was pointed out that a definite relation exists between the determination of sex and the distribution of the sex chromosome. It was noted that the female condition in *Anasa tristis* is always accompanied by the presence of two X chromosomes, while maleness is characterized by a single X. It was also brought out that in other animals in which an inequality in chromosome number of the sexes does not occur, it is always possible to detect a difference in size, shape, or behavior of certain members of the chromosome complex of one sex as compared with the other. It can be

accepted, therefore, that the determination of sex is always associated with a definite distribution of the sex chromosomes. Furthermore, sex may be considered a *unit character* whose gene is located in the sex chromosome, which means that sex is determined after the manner of a Mendelian character.

Sex-linked Inheritance.—The inheritance of characters whose determiners seem to be *linked* with the determiners of sex are sex-linked characters. For example, Morgan found that when the ordinary *red-eyed female* of the fruit-fly, *Drosophila ampelophila,* is bred with a *white-eyed male* mutant of the same species all the F_1 generation is *red-eyed.* Inbred, these produce in the F_2 *red-eyed females, red*-and *white-eyed males,* but no white-eyed females. When the reciprocal cross is made, starting with *white-eyed females* and *red-eyed males,* the *females* of the F_1 are all *red-eyed* and the *males* are all *white-eyed.* In the F_2 one obtains *red-* and *white-eyed males* and *females* in equal numbers. The fact that the *reciprocal* crosses differ at once suggests some connection between eye color and sex in these flies which is a result quite unlike that obtained in ordinary Mendelian crosses in which non-sex-linked characters are always segregated and assorted *independently* of parental origin.

Explanation of Sex-linked Inheritance.—It will be recalled that the chromosomes of the male and female Drosophila do not differ in number, but in the size of the members of one pair. The diploid number of the male is eight (6 + X + Y). That of the female is also eight (6 + X + X). X and Y differ in *size.* Two X chromosomes establish the female condition, while an X and Y combination always produce a male. Now if the assumption is made that the determiner for eye color is located in the X chromosome, and that the Y chromosome does not carry a color gene, the results of the eye-color crosses are satisfactory explained. This is outlined in the accompanying diagrams, (Figs. 160 and 161).

Color blindness in man is also inherited in a similar way. The explanation accounts for the well-known fact that color blindness is much more common in men than in women, the reason for which seems to be that in women *both* X chromosomes must carry the gene for color blindness in order for the condition to develop, while in the male only a *single dose* of the factor is necessary. The Y chromosome is not concerned in color blindness (Figs. 162 and 163.)

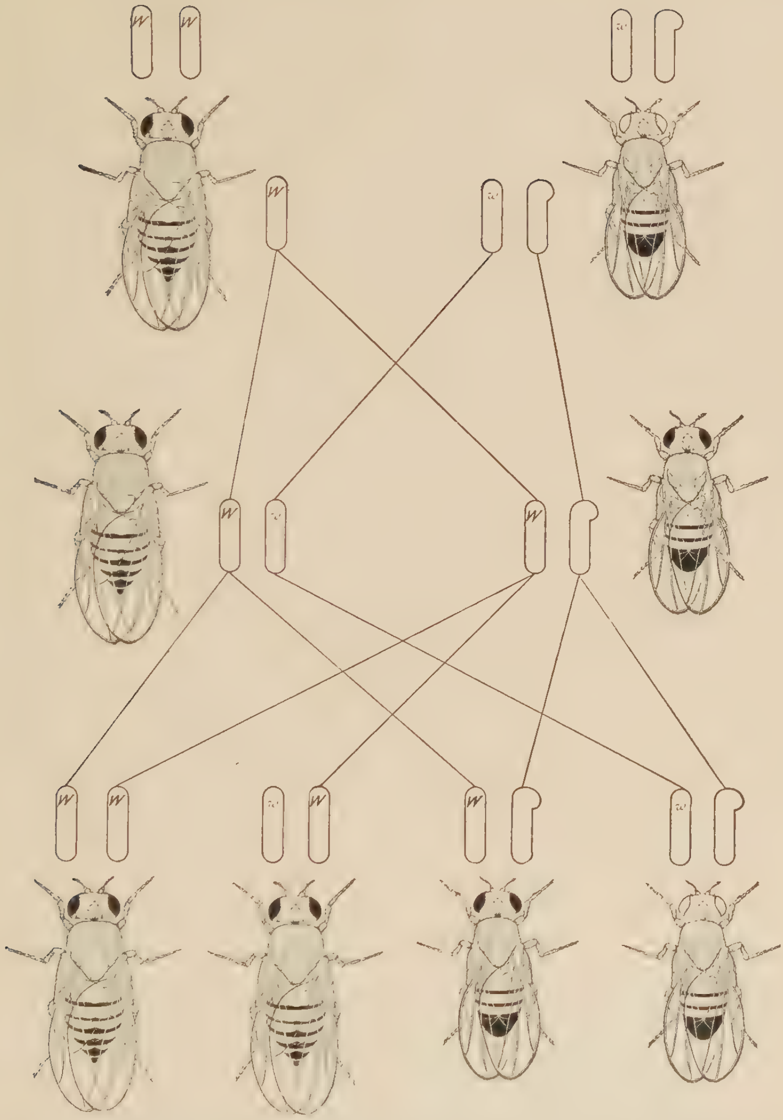


FIG. 160.—Red-eyed female by white-eyed male (*D. ampelophila*). The factors for these characters are carried by the X chromosomes. In this diagram red is indicated by the symbol W and white by w. The history of the chromosomes is shown in the middle of the diagram. (*From Morgan, Physical Basis of Heredity, J. B. Lippincott Company.* By permission.)

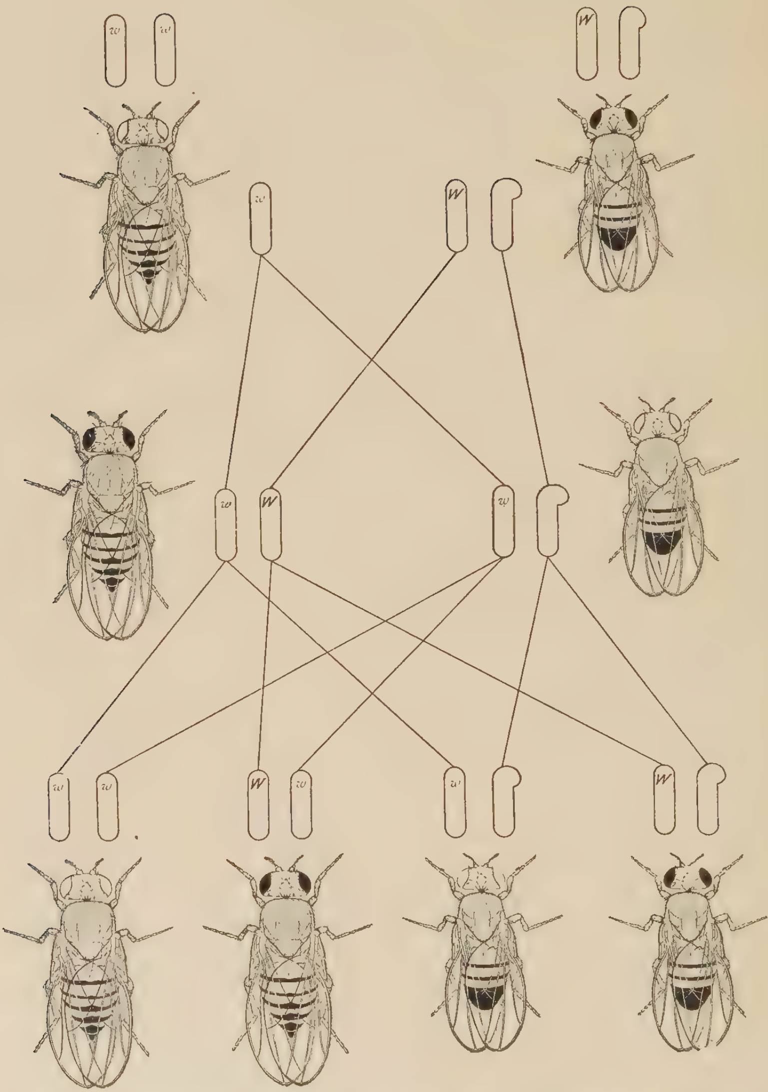


FIG. 161.—White-eyed female by red-eyed male (*D. ampelophila*). This is the reciprocal of the cross shown in Fig. 160. (*From Morgan, Physical Basis of Heredity, J. B. Lippincott Company.* By permission.)

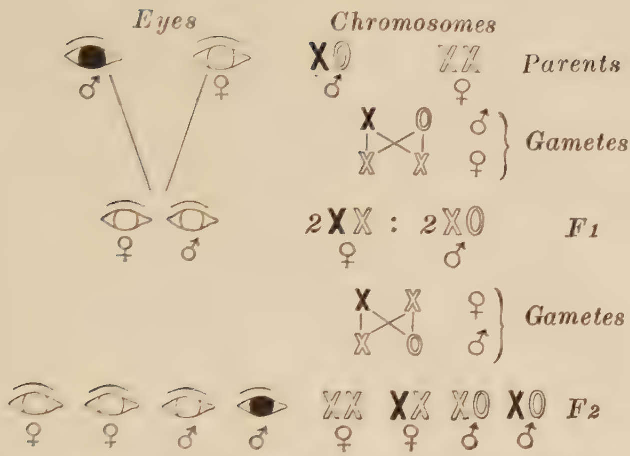


FIG. 162.—Diagram of the inheritance of color blindness through the male. A color blind male (here black) transmits his defect to his grandsons only. The corresponding distribution of the sex chromosomes is shown on the right, the one carrying the factor for color blindness being black. The Y chromosome is shown as an O. *(From Conklin, Heredity and Environment, Princeton Univ. Press, after Morgan. By permission.)*

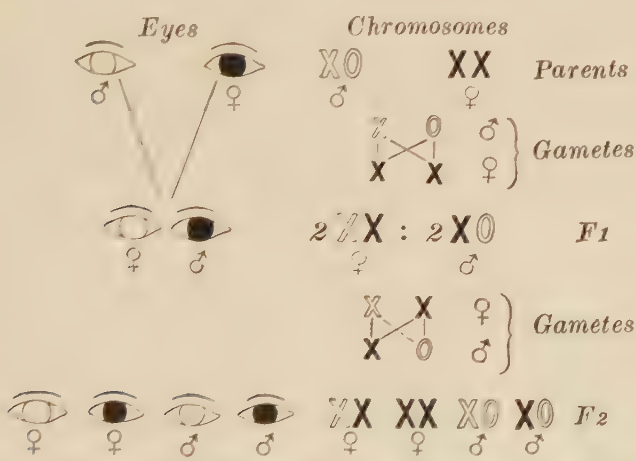


FIG. 163.—Diagram of the inheritance of color blindness through the female. A color blind female transmits the defect to all her sons, to half of her granddaughters and to half of her grandsons. Corresponding distribution of sex chromosomes on the right. *(From Conklin, Heredity and Environment, Princeton Univ. Press, after Morgan. By permission.)*

As shown in the diagrams, none of the children of the first cross are color-blind. The daughters are heterozygous but not color-blind, because only a single dose of the factor is present. In the next generation one-half of the grandsons are color-blind. In the reciprocal cross, the sons of the F_1 are color-blind but not the daughters. In the F_2 one-half of the grandchildren are color-blind.

Crossing Over.—Morgan and others have discovered many instances in which the *expected ratios* in the crossing of two pairs of sex-linked characters have been modified in an unexpected manner. When *yellow-winged* mutants are crossed with wild *gray-winged* forms, the result is similar to that obtained from crossing red and white eyes. The characters are sex-linked, and yellow wing behaves exactly like white eye. Now if a *female* with *white eyes* and *yellow wings* is crossed to a *male* with *red eyes* and *gray wings*, the males of the F_1 have yellow wings and white eyes, and the females gray wings and red eyes. Breeding the F_1 flies produces in the F_2 two classes:

	Per Cent
1. *Yellow wings, white eyes*, males and females; *gray wings, red eyes*, males and females	99
2. *Yellow wings, red eyes*, males and females; *gray wings, white eyes*	1

The result in the first of these two groups is that which would have been expected had the original combinations of yellow wing, white eye and gray wing, red eye remained together in their respective chromosomes. But since in group 2 a new combination of characters appeared in 1 per cent of the entire number, the conclusion is forced that an *exchange of parts of chromosomes* must have taken place, provided, of course, that the original premise that chromosomes are the bearers of these genes is correct. Such a recombination of characters is known as *crossing over*, and it is explained by assuming that in *synapsis* the sex chromosomes of the oöcyte become twisted about each other, so that when they separate two composite chromosomes are formed, as shown in the following diagram. If one assumes, therefore, that such a recombination of chromosomes occurred in 1 per cent of the cases, the results of the cross are explained.

Crossing over also takes place in *non-sex-linked characters*. The wild Drosophila has a gray body and long wings. Black body and vestigial wings occur as mutations. These characters are not sex-linked. If a *female* with *gray body* and *long wing* is mated

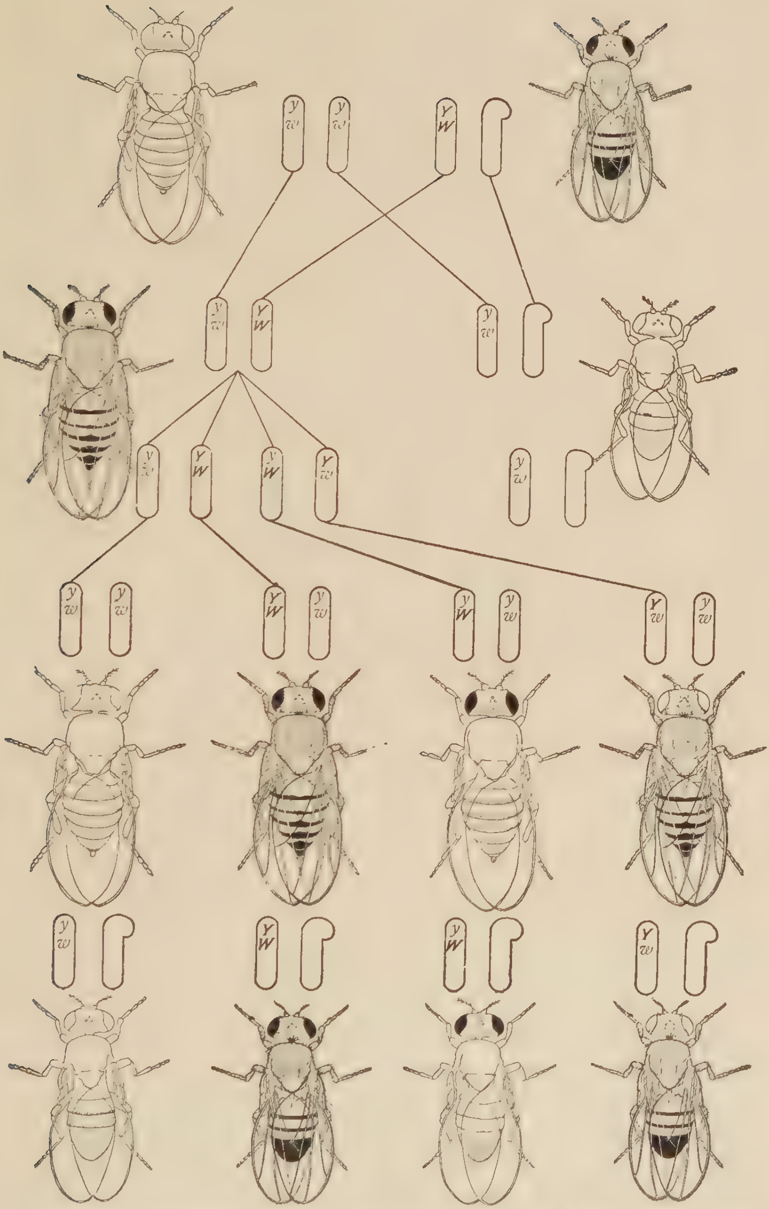


FIG. 164.—Diagram to illustrate the result of crossing a white-eyed yellow-winged female with a red-eyed gray-winged male. Y, gray wing; y, yellow wing; W, red eye; w, white eye. (*From Morgan, Physical Basis of Heredity, J. B. Lippincott Company.* By permission.)

to a *male* with *black body* and *vestigial wing*, the F_1 is *gray* and *long*. The reciprocal cross gives the same result. If an F_1 *female* is crossed to a *black vestigial male*, the following result is obtained:

	Per Cent
1. *Black body, vestigial wings,* males and females; *gray body, long wings,* males and females	83
2. *Black body, long wings,* males and females; *gray body, vestigial wings,* males and females	17

In 17 per cent of the total number there is a crossing over or recombination of characters.

It is interesting to note that the crossover phenomena take place *only* in the female. For example, if one crosses an F_1

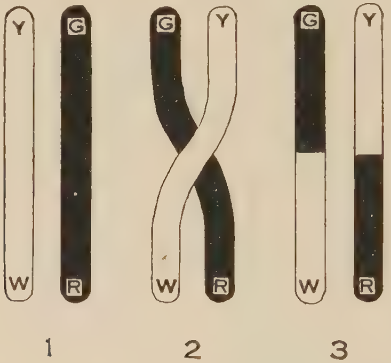


Fig. 165.—Diagram illustrating recombination of characters in crossing over.

male, from the preceding experiment, to a black vestigial female, the result is only two kinds of individuals, namely, gray long and black vestigial. Evidently, in the male there is no recombination of chromosome parts, and hence no crossing over.

Significance of Crossing Over.—It will also be noted that the percentage of crossovers differs in the two examples cited. According to Morgan "Other characters show different values, but the same value under the same conditions is obtained from the same pair of characters." Morgan and his students have interpreted this to mean that the genes for different characters occupy *different* positions in the chromosomes and that, consequently, the nearer together the genes the less likelihood of a twist occurring between them, and the lower the percentage of crossovers. Conversely, the farther apart the genes the higher the number of

chances for crossing over. The *strength of linkage* is in *direct proportion* to the distance separating genes.

Chromosome Maps.—On this basis *maps* have been made of the chromosomes of Drosophila. By experimental breeding it has been learned that *four linkage groups* exist in Drosophila, and *only* four, which, fortunately for the theory, correspond to the *four groups of chromosomes*, three pairs of autosomes and one pair of sex chromosomes. One of the character groups is a sex-linked group, the genes of which are, therefore, assigned to the sex chromosome, the locations being determined by the percentage of crossing over in each case. The division of the three non-sex-linked groups among the autosomes is somewhat uncertain, since there is no way of knowing why a character group should be assigned to any particular chromosome except that the groups differ in size as do the chromosomes. The accompanying figure shows the maps as far as they have been perfected. The figures on the chromosomes indicate the supposed relative distances of the genes from the top of each chromosome. (Fig. 165*A*.)

Value of Drosophila Breeding Experiments.—The work with Drosophila ranks as one of the most brilliant accomplishments in modern biology and goes a long way toward firmly establishing the fundamental postulate that the chromosomes are the bearers of the genes of Mendelian characters. Since Mendelian inheritance is practically universal, this means that the chromosomes are the vehicle of all forms of heredity, as the term is ordinarily used. This in no way conflicts with the idea that the cytoplasm of the egg is also an important factor in development. In all of the Drosophila experiments the hybrids produced are all *flies* of the same species—they differ only in relatively minor details. Perhaps one of the main reasons why flies always breed flies is the *specific nature* of the organization of the egg cytoplasm. In other words, whereas heredity in the common usage of the term refers to relatively superficial *individual characters*, it must not be forgotten that there is also an inheritance of more fundamental *species characters*, the location of whose "genes" may well be situated in the cytoplasm of the egg, as well as in the chromosomes as a whole. Chromosomes appear more prominently in discussions of heredity, because they lend themselves more readily to study and analysis than does cytoplasm, but there is every reason for believing that nucleus

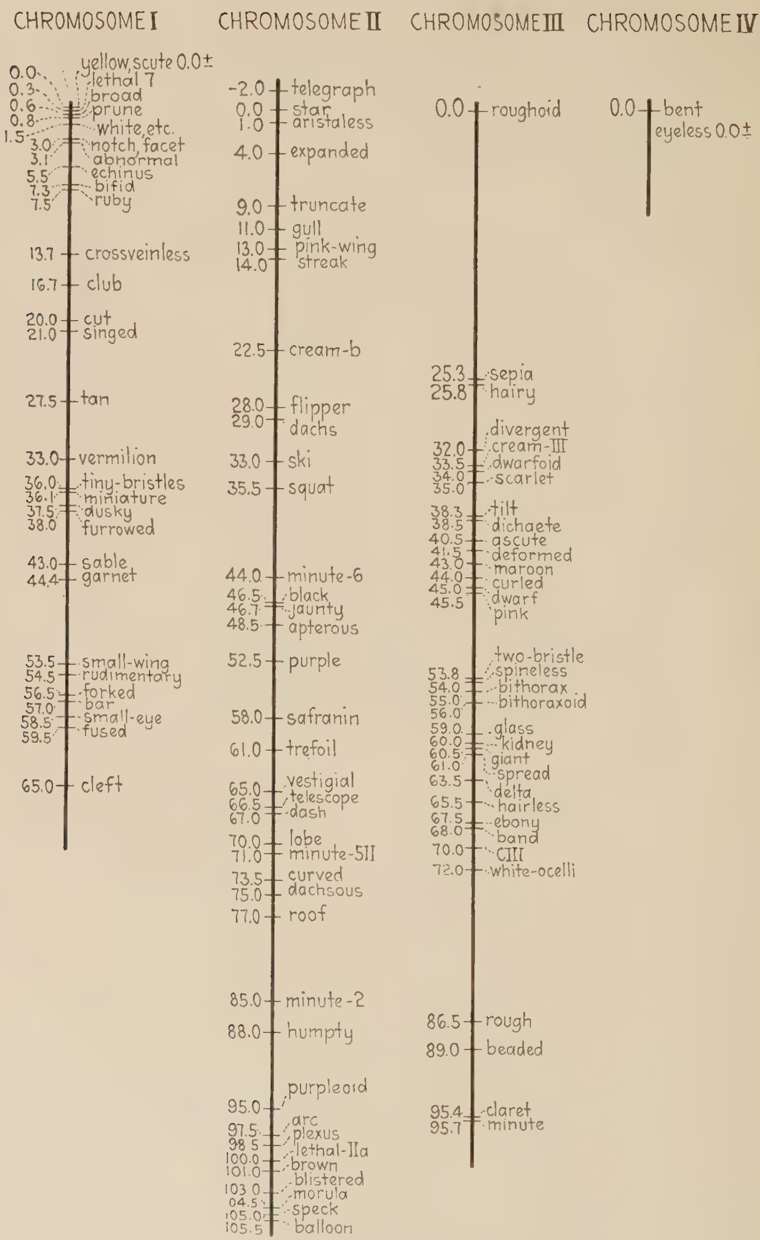


FIG. 165A.—Chromosome map of *D, ampelophila.* (*From Sharp, Introduction to Cytology, after Morgan.*)

and cytoplasm constitute a *metabolic unit* of which the chromosomes are an expression of but *one* phase of the organization.

Eugenics.—The science of the *improvement* of the human race by better breeding or, as Frances Galton, the author of the term, put it, "the science which deals with all influences that improve the inborn qualities of a race is known as eugenics." The argument is simply this: if man has succeeded through artificial selection or controlled breeding in improving domestic animals and plants, it should also be possible by similar means to improve the human race, especially since man constitutes no exception to the laws of heredity governing other animals. Human traits of germinal origin, whether they be *morphological*, *physiological*, or *psychological*, are inherited. Some of these may be desirable, some not, and others may be of neutral value so far as the good of mankind is concerned. A few of the characters of obvious importance to eugenics are discussed in the following paragraphs.

Inheritance of Mental Ability.—In Darwin's own family inheritance of mental ability is illustrated. His paternal grandfather, Erasmus Darwin, was a physician, naturalist, and poet. He was interested in the problem of evolution and offered interesting contributions to it and other subjects. His maternal grandfather was Josiah Wedgwood, the originator of Wedgwood pottery. Darwin's father was a successful physician and Darwin's sons have achieved eminence in science.

Mental Defectiveness or **Feeble-mindedness.**—The antithesis of mental ability also rests upon an hereditary basis. Mental defectiveness implies underdeveloped mentality, and in its extreme form occurs as *idiocy*. Offspring of idiots are always feeble-minded. They are helpless, depraved, irresponsible, and a burden to society. *Criminal tendencies* of a very common sort are usually the result of a feeble-minded condition. They form a prominent feature of the so-called *Jukes* family of New York, whose ancestry has been traced as far as 1772. In five generations that have been studied, it has been ascertained that out of 1,200 individuals, including those who married into it and who were of the same social strata, only *twenty* learned a trade and of these *ten* received their instruction in a state prison. (Kellicott.)

Epilepsy.—A little-understood disease, epilepsy subjects its victims to spasmodic convulsions accompanied usually by loss of consciousness. It is frequently but not always associated with feeble-mindedness and seems to be hereditary. According

to Echeveria, of 533 children of 136 epileptics, 105 were normal, 78 epileptics, 195 died in convulsions in childhood, 39 showed some form of paralysis, 51 were hysterical or choreic, 11 insane, 18 idiots, and the remainder died in childhood (Adami).

Diseases.—In order that a disease caused by *microorganisms* may develop, *infection* by a specific organism or organisms must take place. That children of tuberculous parents often develop tuberculosis is due in part to an inherited *physiological resistance* to infection of a low order, which makes infection more certain than in the offspring of sound, healthy parents. A healthy individual may carry the germs of tuberculosis in the mouth, respiratory passages, or lungs, and yet not show any symptoms of the disease. In other words, disease in parents does not effect their germ cells in such a way as to produce disease in their children in the absence of infection through the usual channels. Theoretically, therefore, and for the most part practically, too, it is possible, by proper precautions against infection and by providing proper food, to rear such children to be healthy adults.

The same is true of other conditions brought about by *pathogenic organisms.* The statement is frequently made that *syphilis,* a most loathsome venereal disease, is hereditary. Practically, this is true, because the children of syphilitic parents are almost invariably syphilitic. But here again it is not the germ cells that are specifically damaged; the opportunities for infection either before, during, or after birth are so great that the offspring rarely escapes.

A list of hereditary conditions important in connection with eugenics follows:

Table 4.—Mendelian Inheritance in Man

Normal characters: Dominant	Recessive
Hair:	
Curly	Straight
Dark	Light to red
Eye color:	
Brown	Blue
Skin color:	
Dark	Light
Normal pigmentation	Albinism
Countenance:	
Hapsburg type (*thick lower lip and prominent chin*)	Normal
Temperament:	
Nervous	Phlegmatic
Intellectual capacity:	
Average	Very great
Average	Very small

Table 4.—Mendelian Inheritance in Man—(*Continued*)

Teratological and pathological characters:

Dominant	Recessive
General size:	
Achondroplasy (*dwarfs with short, stout limbs and heads of normal size*)	Normal
Normal size	True dwarfs (*with all parts of the body reduced in proportion*)
Hands and feet:	
Brachydactyly (*short fingers and toes*)	Normal
Syndactyly (*webbed fingers and toes*)	Normal
Polydactyly (*supernumerary digits*)	Normal
Skin:	
Keratosis (*thickening of epidermis*)	Normal
Hypotrichosis (*hairlessness associated with lack of teeth*)	Normal
Kidneys:	
Diabetes insipidus	Normal
Diabetes mellitus	Normal
Nervous system:	
Normal	General neuropathy, *e.g.*, Hereditary epilepsy, Hereditary feeble-mindedness, Hereditary insanity, Hereditary alcoholism, Hereditary criminality
Normal	Chorea (St. Vitus's dance)
Eyes:	
Hereditary cataract	Normal
Pigmentary degeneration of the retina	Normal
Glaucoma (*internal pressure and swelling of the eye-ball*)	Normal
Coloboma (*open suture in iris*)	Normal
Displaced lens	Normal
Ears:	
Normal	Deaf-mutism
Normal	Otosclerosis (*rigidity of tympanum etc., with hardness of hearing*)
Sex-linked characters:	
Recessive characters, appearing in male when simplex, in female only when duplex.	
Normal	Hemophilia (*slow clotting of blood*)
Normal	Color blindness (*Daltonism; inability to distinguish red from green*)
Normal	Night blindness (*inability to see by faint light*)
Normal	Neuritis optica (*progressive atrophy of optic nerve*)

(From Conklin, "Heredity and Environment," *Princeton University Press.*)

Environment.—It will at once occur to the reader that any attempt to improve the human race by means that fail to take into consideration environmental conditions will not meet with much success. It might be maintained that Darwin owed at least some of his success to his surroundings, his education, and his private means, the latter permitting him to pursue his studies unhampered. Likewise, it might be truly said that a large part of the misfortunes of the Jukes family were due to the miserable environment in which they lived. Both inferences are correct and it must be admitted at once that environmental factors play a large part in a man's success in life; but it must also be recognized that heredity plays an even greater part in one's destiny by fixing *limitations*. A Jukes would never make a Darwin.

Mental Tests.—That differences in the hereditary mental make-up of different individuals actually exists has been demonstrated by quantitative methods in what are known as *mental tests.* These tests, while not infallible, have been carefully worked out for the purpose of comparing outstanding features of the mental equipment of different individuals. They are standardized according to *age,* so that is possible to determine if a given individual is up to the standard of the average normal person of his age. An unusual opportunity for applying these tests on a large scale presented itself when recruits were examined for the American army during the World War, and the startlingly low mental records made by some of those refused for service furnishes a rather discouraging outlook for many fellow citizens. Such tests emphasize the fact of the *inequality* of human mentality, the fact that all men are *not* born equal in a biological sense.

Aim of Eugenics.—In animal breeding, man establishes an arbitrary standard, in the selection of which the animal has no voice. In human breeding, such a procedure is impossible, except to the extent permitted by society as a whole, when it grasps the truth of the fact that certain types of individuals are undesirable, and therefore, not worthy of the privilege of reproducing their kind. A *eugenics program* at the present time can have no one individual in mind as a type for which all should strive, but it can aim at the general adoption of a policy which will gradually *eliminate* the unfit. The most practical steps directed toward this end seem to be:

1. *To promote intelligent marriages,* by which is meant that marriages should be forbidden between persons obviously mentally defective, or unfortunate enough to be afflicted with practically incurable diseases like gonorrhea or syphilis;

2. *To prevent reproduction* among the mentally and socially unfit. In many cases this is enforced among certain classes of criminal offenders by the performance of a surgical operation which renders the patient sterile. *Vasectomy* is practiced on the male by removing a small section of each *vas deferens,* which prevents the passage of sperm to the outside. In the female, a small piece of each *Fallopian tube* (oviduct) is excised, so that eggs cannot reach the uterus, or be fertilized.

The ultimate adoption of a eugenics program rests upon *education.* Ignorance of the facts forms the bulwark of resistance

to plans which at first sight savor of infringement on personal liberty, but which more mature consideration prove to be merely an honest attempt to raise the general physical and mental level of society as a whole and with it the individual happiness of its members.

References

Babcock, E. B. and Claussen, R. E.: "Genetics in Relation to Agriculture," McGraw-Hill Book Company, Inc., 1918.

Castle, W. E.: "Genetics and Eugenics," Harvard University Press, 1924.

Conklin, E. G.: "Heredity and Environment in the Development of Men," Princeton University Press, 1916.

Guyer, M. F.: "Being Well Born," Bobbs-Merrill Company, 1916.

Kellicott, W. E.: "The Social Direction of Human Evolution," D. Appleton & Co., 1911.

Morgan, T. H.: "The Physical Basis of Heredity," J. P. Lippincott & Company, 1919.

CHAPTER XIX

GENERAL SURVEY OF THE ANIMAL KINGDOM

The following pages contain an account in the nature of a *synoptic review* of the animal phyla in which the principal characteristics upon which the present system of classification is based are briefly discussed. Owing to the general character of the treatment and the extent of the ground to be covered, it is possible to consider only such details of classification as are deemed necessary for a general understanding of the *principles* underlying the arrangement of animals in groups; for the same reasons, groups of uncertain systematic position are omitted entirely. In citing examples of animals illustrating the smaller subdivisions of a phylum, either the scientific name is given, consisting of the *Genus* followed by the name of the *Species*, or the *Generic* name alone. The *common name* is also cited in all cases where a common name is in use.

Purpose.—A systematic review of the animal kingdom at this point enables one to understand more clearly the applications of the general biological principles dealt with in the preceding chapters and also to fix in mind the *terminology* of classification. Many of the taxonomic terms have become more or less familiar by this time both from the work in the laboratory and from the references in the text, but a somewhat more definite consideration of the systematic side of zoology is desirable, since without a knowledge of the names and general arrangements of the animal phyla and their subdivisions, together with the names and the characteristics of forms constituting the groups, a general survey of the field of zoölogy would be incomplete.

PHYLUM I—PROTOZOA

Knowledge of the existence of the group of organisms now known as Protozoa dates from 1675, when they were observed by Leeuwenhoek, whose pioneer work with the microscope brought to light much that up to his time had been unknown of a large variety of microscopic objects. Protozoa (primitive animals)

are so called because they are single-celled animals that lack true organs and tissues, *i.e.*, organs and tissues as they are understood in higher animals. The simplicity of their organization is, however, largely a matter of *minuteness in size*, as has already been pointed out (Chap. III), for they do have well-developed cell organs (*organelles*), such as food vacuoles and contractile vacuoles, and highly differentiated structures, such as pseudopodia, cilia, or flagella. Some, like amœba, have no mouth, but others, like paramœcium, have a permanent *cytostome* where food enters, and a *cytopyge* where undigested matter is discharged. Protozoa are found everywhere, in water, soil, the air, and in the bodies of other animals. In the air they are in an *encysted* condition which prevents desiccation and allows them to be carried about by air currents. As parasites, they cause a large number of pathological conditions in man and other animals. The *life histories* of Protozoa are interesting and often very complicated, as may be seen from the examples chosen for illustration in the following paragraphs.

Paramœcium Aurelia.—A common ciliated protozoan occurring as a free-living form in fresh water is *Paramœcium aurelia*. It has a cytostome, gullet, and cytopyge; contractile and food vacuoles; a large macronucleus and two small micronuclei. If samples from a culture of this protozoan are kept under continuous observation, it is found that at fairly regular intervals *binary fission* takes place and a single individual divides into two daughter cells. Each of the latter grows, and in about ten hours attains the size-limit characteristic of the species, when division again occurs. A large number of binary fissions may take place after this fashion; but sooner or later, under ordinary conditions in a laboratory culture, an entirely different sort of phenomenon, known as *conjugation*, occurs. In this process two individuals touch, at first in front, and then along the entire surface of one side, so that the cytostomes come together; the *macronucleus* swells and breaks up, the fragments eventually dissolving; and the *micronuclei* by two successive divisions produce *eight* nuclei in each conjugant. *Seven* of these nuclei disintegrate while the *eighth* divides, forming a *stationary* micronucleus and a *migratory* micronucleus. Each migratory micronucleus then passes into the opposite cell and fuses with the stationary micronucleus to form a *synkaryon* or fertilization nucleus. The conjugants now separate and in each the synkaryon divides twice, producing

four micronuclei, two of which are transformed into macronuclei. The two remaining micronuclei each divide again, accompanied by a division of the cell, so that two complete individuals, each provided with a macronucleus and two micronuclei are derived from each of the conjugants.

Woodruff has shown that if the medium in which isolated paramecia are living is kept fresh by constant changing, conjugation does not occur for thousands of generations (12,000, in the

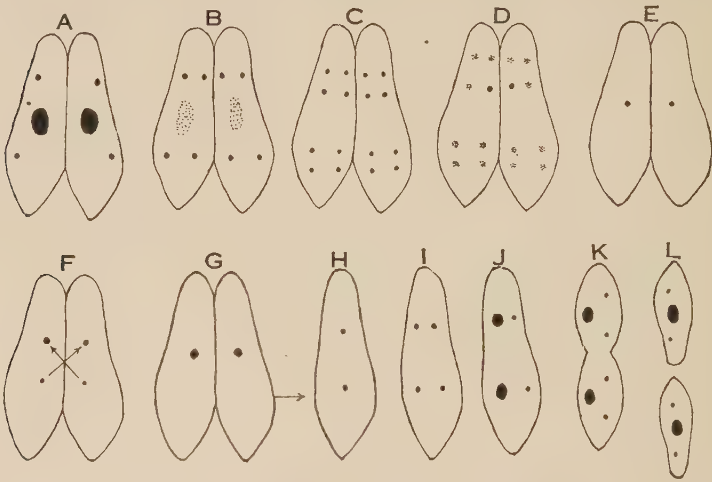


FIG. 166.—Diagram of the nuclear changes in *Paramœcium aurelia* during conjugation. A, union of conjugants; B, degeneration of macronuclei and first division of micronuclei; C, second division of micronuclei; D, degeneration of seven of the eight micronuclei in each conjugant; E, each conjugant with a single micronucleus, which in F has divided into a stationary and micronucleus; G, each conjugant with a synkaryon formed by the fusion of the migratory nucleus of one with the stationary nucleus of the other conjugant; H, first reconstruction division of the synkaryon to form two micronuclei (takes place in each of the conjugants which now separate); I, second reconstruction division of the micronuclei; J, two micronuclei transformed into two macronuclei; K, division of two micronuclei and division of cell; L, two complete new individuals. (*After Woodruff, Foundations of Biology, copyright, The Macmillan Co. By permission.*)

period from 1907 to 1921). It was found, however, that every forty or fifty generations the macronucleus degenerates and is replaced by chromatin from the micronucleus, a process known as *endomixis.* The nuclear changes, as may be seen from the figure, are similar to those occurring in conjugation, except that there is no exchange of nuclear material between two individuals; *i.e. reciprocal fertilization* does not occur. The common feature of both conjugation and endomixis, namely, the periodic replace-

ment of the macronucleus with material from the micronucleus, would seem to have some significance as a means of *rejuvenesence* that must take place from time to time in order to maintain life.

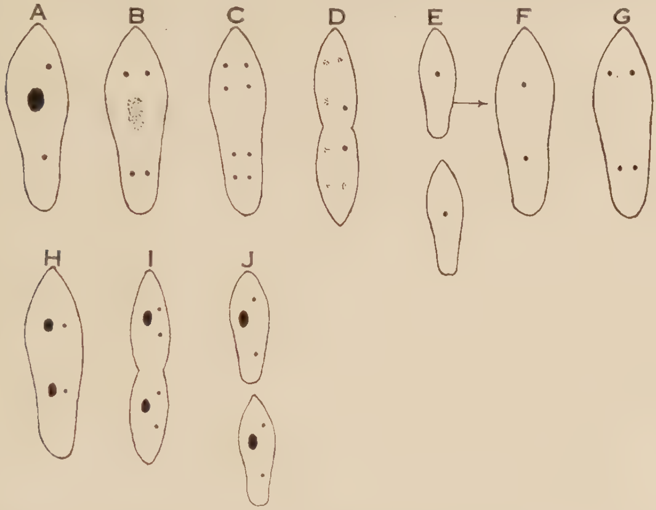


FIG. 167.—Diagram of the nuclear changes in Paramœcium aurelia during endomixis. A, typical nuclear condition; B, degeneration of macronucleus and first division of micronuclei; C, second division of micronuclei; D, degeneration of six of the eight micronuclei; E, cell division; F, first reconstruction division of micronuclei; G, second reconstruction division; H, transformation of two micronuclei into two macronuclei; I, division of micronuclei and cell division; J, two complete new individuals. (*After Woodruff, Foundation of Biology, copyright, The Macmillan Co. By permission.*)

Plasmodium Vivax.—*Tertian malaria* in man is caused by a pathogenic protozoan, *Plasmodium vivax.* The *asexual* phase of its life cycle is passed in the female of a certain species of mosquito belonging to the genus *Anopheles*, while the *sexual* phase is passed in man.

The salivary glands of a mosquito capable of infection carries *sporozoites*, which are spindle-shaped cells, 10 to 12 microns in length. These are introduced into the wound when the mosquito bites a human being. In the human blood stream the parasite bores into a red blood corpuscle, where it takes on an amœboid shape known as the *trophozoite* stage. On reaching its full growth, the trophozoite undergoes segmentation or *shizogany*, as it is called, to form spores or *merozoites*, which are liberated in the blood stream by the rupture of the corpuscle, about forty-eight hours after infection. The freed merozoites attack fresh cor-

puscles and the cycle is repeated, and each time the corpuscles break down, the *chill* characteristic of malaria occurs. After several generations of merozoites have been produced, two kinds

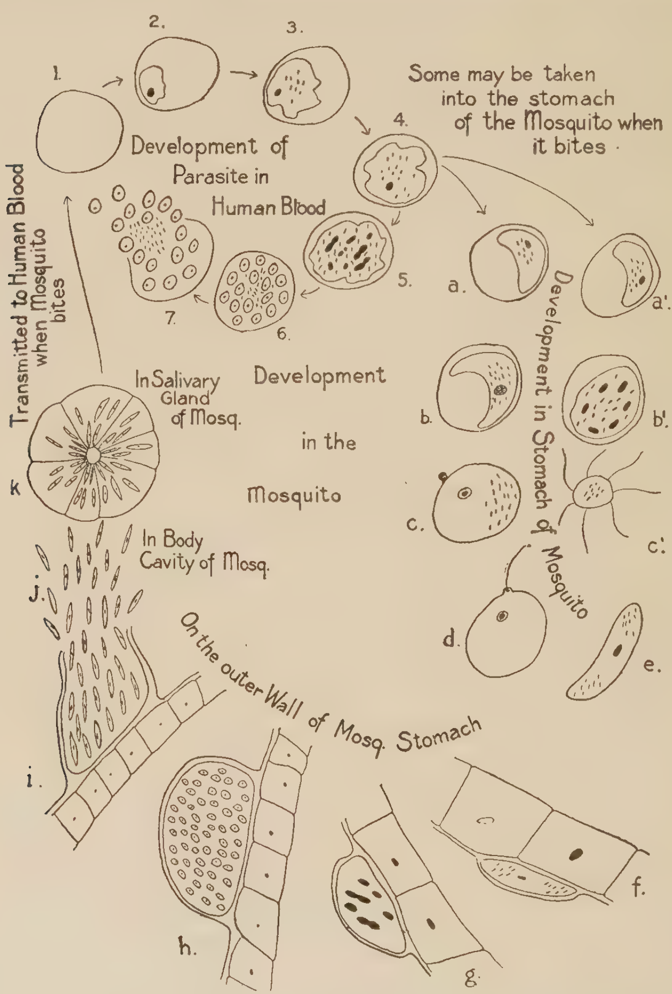


FIG. 168.—Diagram illustrating the life history of malarial parasite. 1, red blood corpuscle; 2–7, shizogony; *a*, *b*, *c*, *a'*, *b'*, *c'*, development of gametocytes; *d*, zygote; *e*, oökinete; *f*, *g*, *h*, development of oöcyst; *i*, liberation of sporozoites; *k*, section of salivary gland. (*From Doane, Insects and Disease, H. Holt & Co. By permission.*)

of gametocytes are formed, *macrogametocytes* and *microgametocytes*. The factors determining the development of the merozoites into gametocytes instead of trophozoites are unknown.

For further development, the gametocytes must pass into the stomach of the mosquito, a transfer readily brought about when a mosquito bites a patient containing them. The macrogametocyte undergoes certain nuclear changes somewhat akin to polar-body formation and is thus transformed into a *macrogamete.* Each microgametocyte, on the other hand, produces from six to eight whip-like *microgametes.* A single microgamete enters a macrogamete, with which it fused to form the *zygote.* The zygote in the course of twenty-four hours is transformed into an active *oökinete,* which bores into the stomach wall, in the outer layers of which it forms the *oöcyst.* The latter grows in size and then divides to form sporoblasts, each of which, in turn, forms a number of sporozoites. The oöcyst bursts, liberating the sporozoites in the body cavity, whence they find their way *via* the body fluids to the salivary glands.

Tertian malaria is so called because the chill comes at the end of forty-eight hours, *i.e.*, on the third day. Other forms of malaria have a different incubation period and are caused in each case by a different species of parasite. The life histories are all similar to that of P. vivax given above, though differing in details.

A Classification of Protozoa, showing the principal subdivisions, follows. The method of locomotion is made the basis of the division of the phylum into four classes:

CLASS I. SARCODINA.[1] Protozoa having *pseudopodia.*

SUBCLASS 1. RHIZOPODA. Creeping forms with *root-like* pseudopodia.

Order 1. **Lobosa.** Undergo a constant change in the shape of the body, the so-called "amœboid" movement.
Examples: Amœba proteus, a common fresh-water form; *Endamœba histolytica,* a parasite producing ulcers in the liver and intestines of man.

Order 2. **Proteomyxa.** No shells. *Flagellated* and heliozoan-like stages may occur.
Example: Pseudopoca volvocis, parasitic on volvox.

Order 3. **Foraminifera.** A *shell* with an opening though which pseudopodia are extended. Chalk beds are largely composed of the skeletons of this group.
Example: Difflugia urceolata, found in fresh water.

[1] The classification of Sarcodina and Mastigophora follows the arrangement in Hegner and Taliaferro: "*Human Protozoology,*" The Macmillan Co., 1924.

Order 4. **Mycetozoa.** Suggest the appearance of a gigantic amœba containing many nuclei. They occur as bright-red, orange, or yellow patches of slime on decaying wood and are regarded a plant by some because their reproductive organs (sporangia) resemble those of fungi.
Example: Æthalium.

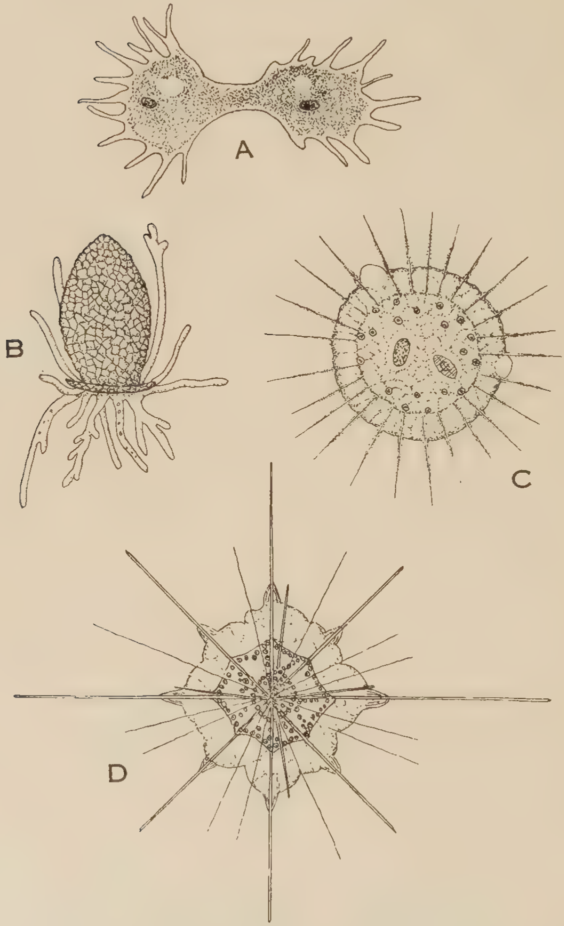


FIG. 169.—A, *Amœba polypodia*, dividing. (*After Schulze.*) B, *Difflugia urceolata*, a foraminiferan having a shell composed of grains of sand held together by chitin. (*After Leidy.*) *Actinospherium eichhorni*, a multinucleted heliozoan without a skeleton; the oblong objects in the medullary region are food particles; two contractile vacuoles are shown in the cortex. (*After Hertwig.*) D, *Acantho metra elastica*, a radiolarian with a spiny skeleton; the central capsule contains a large number of small rounded nuclei. (*After Hertwig.*) (*A, C, D, redrawn from Hertwig's Manual of Zoology, by Kingsley, Henry Holt & Co.*)

SUBCLASS 2. ACTINOPODA. Floating forms with *radiating unbranched tentacles.*

Order 1. **Heliozoa.** A spherical body with fine ray-like pseudopodia, and often a *siliceous skeleton,* principally fresh-water forms.
Example: Actinospherium.

Order 2. **Radiolaria.** A spherical body, but having a central part enclosed by a membrane, the *central capsule,* outside of which is the *extracapsulum. Siliceous skeletons,* through which delicate pseudopodia project, are usually present. Exclusively marine.
Example: Acanthometra elastica.

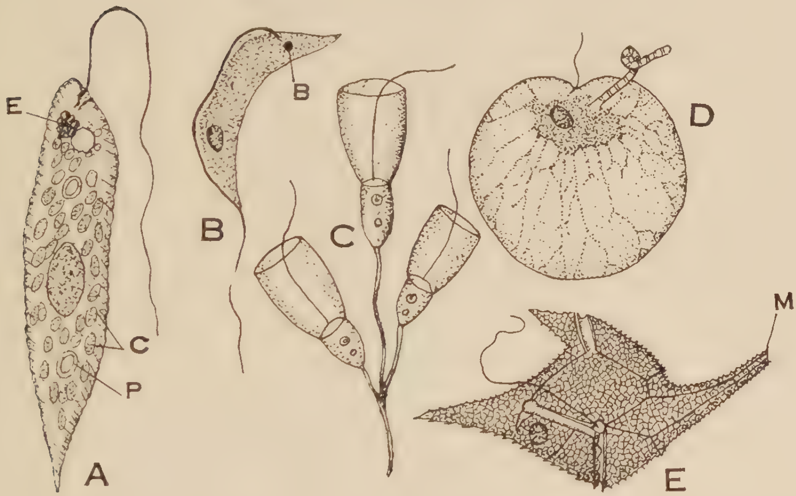


FIG. 170.—A, *Euglena viridis,* a flagellate, showing the striated cuticle. C, chromatophores; E, eyespot; P, pyrenoid body. (*After Bourne.*) B, *Trypanosoma lewisi,* from rat's blood. B, blepharoplast, a nuclear structure. (*After Laveran and Mesnil.*) C, *Codosiga,* a choanoflagellate. (*After Kent.*) D, *Noctiluca miliaris,* a cystoflagellate. (*After Cienkowski*). E, *Ceratium cornutum,* having an armor of cellulose plates. (*After Stein.*)

CLASS II. MASTIGOPHORA, Protozoa having one or more *flagella.*

SUBCLASS 1. ZOÖMASTIGINA. *Animal-like* flagellates.
Examples: Urophagus rostratus, a free-living form; *Trypanosoma gambiensis,* a *blood parasite* causing African sleeping sickness in man, transmitted by *Glossina palpis,* the tsetse fly.

SUBCLASS 2. Phytomastigina. *Plant-like* flagellates. Usually have a cup-shaped green *chromatophore,* and are enclosed by a rigid cellulose membrane.
Examples: Euglena viridis, a common pond form; *Ceratium,* an armored form; *Noctiluca,* a phosphorescent marine form.

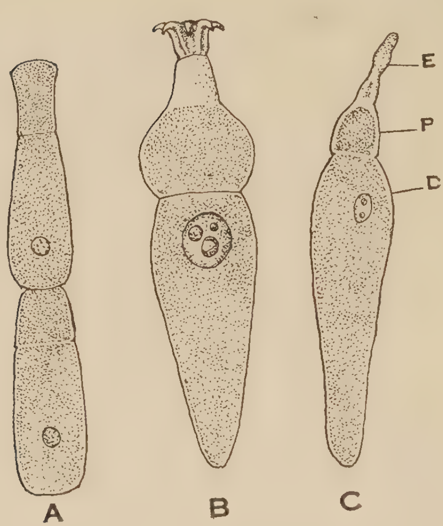


FIG. 171.—Gregarines. A, *Clepsidrina blattarum*, showing a chain of two individuals. (*After Cuenot.*) B, *Corycella armata.* (*After Leger.*) C, *Stylorynchus longicollis.* (*After Schneider.*) E, epimerite; by means of which the parasite is attached to tissues of the host; P, protomerite; D, deuteromerite.

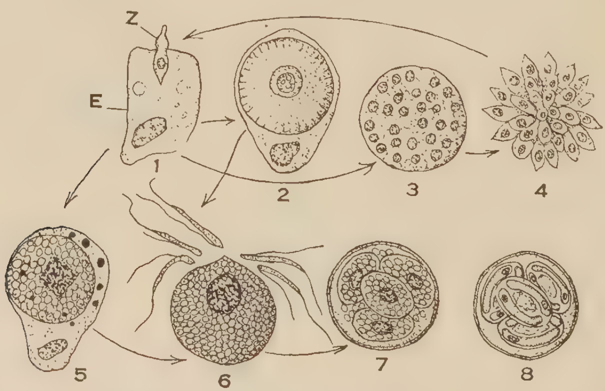


FIG. 172.—Life history of *Coccidium schubergi*, parasitic in the intestinal epithelium of the centipede, *Lithobius forticatus.* (*After Schaudinn.*) Cysts (8) swallowed with food are dissolved by digestive fluid. Each cyst contains four spores each of which in turn contains two sporozoites. The sporozoite attacks the intestinal cell (1), enlarges to form a schizont (3) which undergoes a rapid nuclear division eventually forming merozoites (4). The latter reinfect other cells, repeating the cycle. Sooner or later schizogony is replaced by sporogony which leads to the formation of microgametocytes (2) and macrogametocytes (5) Fig. 6 shows a macrogamete surrounded by a number of microgametes. The fertilized macrogamete becomes encysted, forming four sporoblasts (7) each of which develops two sporozoites (8). The latter remain encysted until favorable conditions arise for their development in another host.

CLASS III. SPOROZOA. Protozoa with a *spore stage* in reproduction. They lack organs of locomotion and are all *parasitic.*

SUBCLASS 1. TELOSPORIDA. Termination of the adult life is marked by spore formation.

Examples: Gregarina, found in the gonads and intestine of invertebrates; *Hæmogregarina,* in the blood cells of the frog; *Coccidium schubergi,* parasitic in the intestine of the centipede; *Isospora hominis* in the human intestine; *Plasmodium vivax,* the malaria parasite, *cytozoic* in the blood cells of man.

SUBCLASS 2. NEOSPORIDA. Spores formed during the growth of the adult. *Examples: Myxobolus,* in the alimentary tract and other organs of fishes; *Sarcosystis miescheriana,* in the muscle tissue of the mouse.

FIG. 173.—*Sarcocystis miescheriana,* from the pig's diaphragm. The organism, enclosed in a cyst, has divided into numerous alveoli, each containing a number of spores some of which are shown free where the cyst has been cut open. *(After Manz.)*

CLASS IV. INFUSORIA. *Ciliated* Protozoa having a definite cuticle; usually a *cytostome* and *cytopyge;* a single macronucleus and one or more micronuclei. All the examples below are fresh-water forms of common occurrence.

SUBCLASS 1. Ciliata.

ORDER 1. **Holotricha.** Cilia uniformly distributed over the entire body. *Example: Paramœcium aurelia.*

Order 2. **Heterotricha.** A tract of stronger cilia near the cytostome. *Example: Stentor.*

Order 3. **Peritricha.** An *adoral* ciliated spiral. The body attached by a *stalk.*
Examples: Carchesium, Vorticella.

Order 4. **Hypotricha.** A *ciliated spiral.* Rows of cilia or *coalesced cilia* on the ventral surface.
Example: Stylonichia.

SUBCLASS 2. **Suctoria.** Ciliated only in the young stages. Adult is *attached* and feeds through *suctorial tentacles.*
Example: Tokophrya.

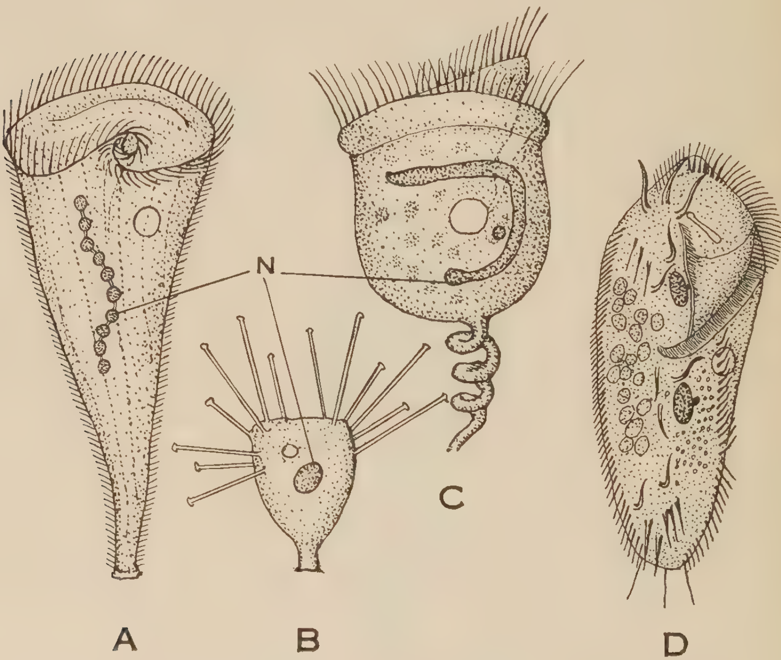


FIG. 174.—Infusoria. *Stentor.* B, *Tokophrya.* (*After Hertwig*) C, *Vorticella.* D, *Stylonichia mytilus.* (*After Stein.*) N, macronucleus.

METAZOA

All animals above Protozoa are collectively known as *Metazoa* The general characteristics which distinguish them from Protozoa may be summarized as follows:

1. The metazoan develops from a fertilized or, less commonly, an unfertilized *egg*. The latter segments into *blastomeres*, which adhere to one another, and in the course of time give rise to *tissues* and *organs* made up of many cells.

2. At least two *germ layers* develop: an *ectoderm* forming the external covering and an *endoderm* lining the alimentary canal

and its appendages. Between these in all higher forms a third germ layer, the *mesoderm*, appears, from which muscle, vascular tissue and other organs develop.

3. There is a *physiological division of labor* among the cells of the metazoan body, a specialization in structure and function.

4. *Sexual cells*, or *germ cells*, are in many cases differentiated from the body, or somatic cells. A sharp distinction between germ and somatic cells has not, however, been demonstrated in all groups, especially the lower ones.

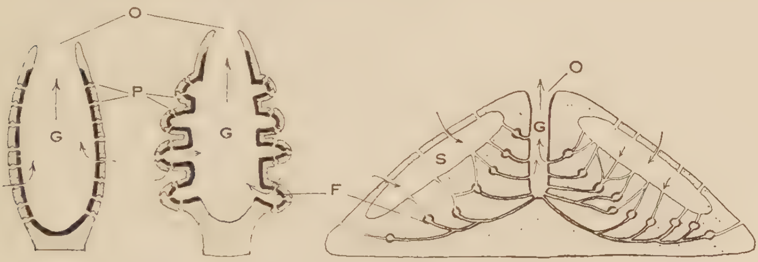


FIG. 175.—Diagrams of three structural types of sponges. A, *Ascon* type; B, *Sycon* type; C, *Rhagon* type. The dermal epithelium is indicated in light line, the gastral epithelium in heavy black. Since the outer layer of the sponge larva becomes the inner layer of the adult, there is some difficulty in applying the terms ectoderm and endoderm. As it is, the dermal epithelium corresponds in position to the ectoderm of other forms and the gastral epithelium to the endoderm. F, flagellated chamber; G, gastral cavity; O, osculum; P, incurrent pores; S, subdermal cavity.

PHYLUM II—PORIFERA

Porifera are sponges. They are *sessile*, aquatic animals whose body walls are pierced with *pores* that admit water to a *cloacal chamber*, which opens to the outside by an *osculum*. Three types of body structure are usually distinguished: (1) the *Ascon* type, having the form of a simple tube; (2) the *Sycon* type, with thicker walls that contain redial canals between the pores and the cloaca; (3) the *Rhagon* type, with still thicker walls, and with radial canals widened into flagellated chambers. Sponges are *radially symmetrical*, which means that the structural pattern is referable to a circle.

The body is made up of an outer covering of flattened and, usually, *non-ciliated* cells; an inner lining of *flagellated collar cells* (chaonocytes) lining the cavities; between these two a layer of *mesoglœa*. The latter is made up of (1) calcareous or siliceous *spicules;* (2) *spongin*, a tough fibrous substance; (3) cellular

elements of two sorts: (*a*) *sceleroblasts* and *spongioblasts*, which secrete spicules and spongin respectively, and are derived from the ectoderm; (*b*) *archeocytes*, which, among other functions that have been ascribed to them, give rise to germ cells. Spongin is the substance of which the commercial sponge is composed. The thickness of the mesoglœa varies considerably in different species.

Sponges react to external stimulation but the responses are sluggish. The ectoderm contains contractile cells, *myocytes*,

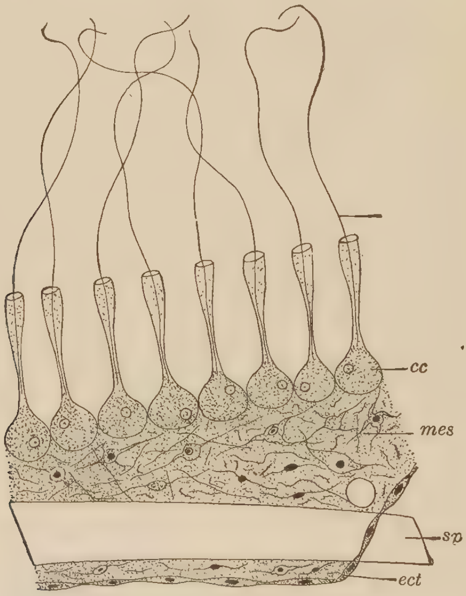


FIG. 176.—Portion of cross section of *Grantia*, a Sycon type of sponge. *cc*, choanocytes; *ect*, dermal epithelium; *fl*, flagellum of choanocyte; *mes*, mesoglœa; *sp*, portion of spicule. (*From Shull, LaRue and Ruthven, Animal Biology.*)

around the osculum and pores; well-developed muscles, nerves, and sense organs are absent. There is no special excretory or respiratory system.

Sponges reproduce by *budding*, *gemmule formation*, and *sexually*. Gemmule formation takes place at the approach of unfavorable conditions caused by high or low temperature, and consists in the accumulation of archeocytes in the mesoglœa to form capsules which are known as gemmules. In temperate zones at the approach of winter, the sponge dies and the gemmules fall

to the bottom where they remain until spring, when they develop into sponges. Gemmule formation occurs in all fresh-water sponges and in some marine forms also.

H. V. Wilson has found that dissociated cells, freed by crushing the sponge, are capable of organizing a new individual. It is a form of *regeneration* of a remarkable sort. The polarity of the new individual is determined by a differential between the free and attached surface, the osculum developing from the free surface.

Sponges are divided into three classes as follows:

CLASS I. CALCAREA. Small marine sponges with *calcareous spicules.*
Example: Grantia ciliata.

CLASS II. HEXACTINELLIDA. *Glass sponges,* with spicules, usually six rayed.
Example: Euplectella aspergillum, Venus' flower-basket.

CLASS III. DEMOSPONGIAE. Usually large, with thick walls containing *flagellated chambers.* The skeleton consists of siliceous spicules and spongin in varying amounts; either or both may be absent.
Examples: Spongilla lacustris, common fresh-water sponge; *Hippospongia gossipina,* one of the commercial sponges.[1]

PHYLUM III—CŒLENTERATA

There are two morphological types among cœlenterates: (1) the *polyp* or *hydroid* form, which is sessile, and (2) the *jelly fish* or *medusoid* form, which is free-swimming. The polyp type is illustrated by *Hydra,* whose body is a double-walled, tubular sac with a fringe of six tentacles around its open, free end. Its body wall consists of an outer *ectoderm* and an inner *endoderm,* lining the *gastrovascular cavity* (cœlenteron), and a trace of a third germ layer in the form of *mesoglœa,* between the two. The gastrovascular cavity extends into the tentacles. The medusoid type is illustrated in its simplest form by *Gonionemus,* the convex side of whose bell-shaped body, the *exumbrella,* corresponds to the attached, blind end of the polyp, while the open end of the *manubrium,* a tube depending from the convex side (*subumbrella*), corresponds to the mouth end of the polyp. In jellyfishes the mesoglœa layer is thickened and jelly-like.

The ectoderm, in addition to typical epithelial cells, contains at its inner border *interstitial cells, epithelial muscle fibers,* and

[1] The classification of the invertebrate Metazoa with the exception of insects follows Pratt: "*A Manual of the Common Invertebrate Animals, Exclusive of Insects.*" A. C. McClurg & Co., 1916.

nerve cells. The latter, in polyps, form a loose network, but in medusoid forms there is a double nerve ring in the outer rim of the umbrella, which also contains sense organs. The ectoderm of the tentacles and other parts of the body is armed with *nettle cells,* which discharge a thread-like tube together with a poisonous fluid when a small spine on the outer side of the nettle cell, the *cnidocil,* is stimulated.

In strong contrast with sponges, cœlenterates are capable of quick *movements* which give them a more animal-like character. This is due, of course, to the more highly developed neuromuscular mechanism.

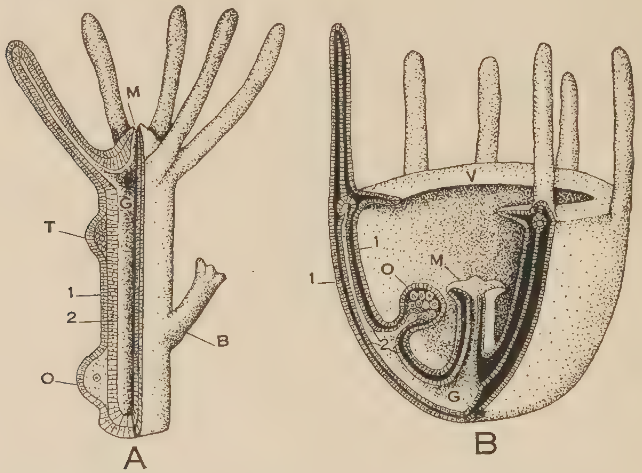


FIG. 177.—Diagrams for comparing the *polyp* type, A, with the *medusa* type, B. 1, ectoderm; 2, endoderm; B, bud; G, gastrovascular cavity; M, mouth; O, ovary; T, testis; V, velum. Mesoglœa is shown in solid black.

The endodermal cells lining the blind gastrovascular cavity are digestive in function. Food enters the mouth and undigested matter leaves at the same opening. The alimentary canal is *incomplete.*

The germ cells are said to arise from ectodermal cells in the lower Cœlenterata and to form the endoderm in the higher ones. It is difficult to maintain that a line of "*germinal continuity*" or a germ track, distinct from the somatic cells, exists in this group. In Hydra, the testis develops as a swelling in the ectoderm of the body wall just below the tentacles; the ovary as a similar swelling nearer the basal disc. This ovary develops a single egg, which after fertilization undergoes development

as far as gastrulation, when it bursts from the ovarian capsule as a free individual.

In general, reproduction is *agamic*, by budding or fission, and *gamic*. In many of the Hydrozoa, as pointed out below, there is *metagenesis* in the life cycle, an alternation of polyp

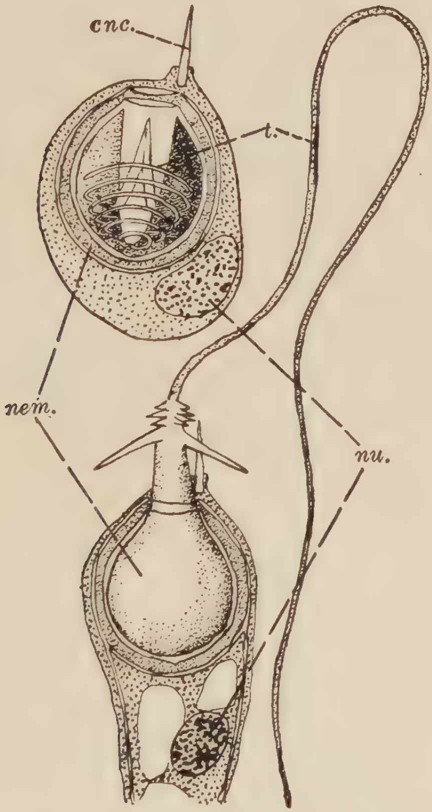


FIG. 178.—Nematocysts of *Hydra* before and after discharge. *cnc*, cnidocil; *nem*, nematocyst; *nu*, nucleus of cnidoblast; *t*, thread-like tube. (*From Dahlgren and Kepner, Principles of Animal Histology, copyright, The Macmillan Co., after Schneider. By permission.*)

with medusa generations. The polyp, developing from a fertilized egg, is asexual, producing by budding the medusæ, which are male or female.

Cœlenterata are divided into three main classes as follows:

CLASS I. HYDROZOA. Radially symmetrical, sessile, and usually colonial, polyp forms; and free-swimming sexual medusae; both sometimes occurring in the life history of a single species. Without going into the intracies of classification, these different conditions may be illustrated by the following:

Hydra viridis, the common, fresh-water, hydra, has a *polyp* stage only. *Gonionemus murbachi*, a marine, *craspedote medusa* (*i.e.*, having a velum extending inward from the edge of the subumbrella), has practically a medusoid stage only, its polyp stage being minute and of short duration. *Obelia dichotoma*, a marine form, has a definite *alternation of generations*, the colonial polyp producing sexual buds (*gonosomes*) that develop into free-swimming male and female medusae. The

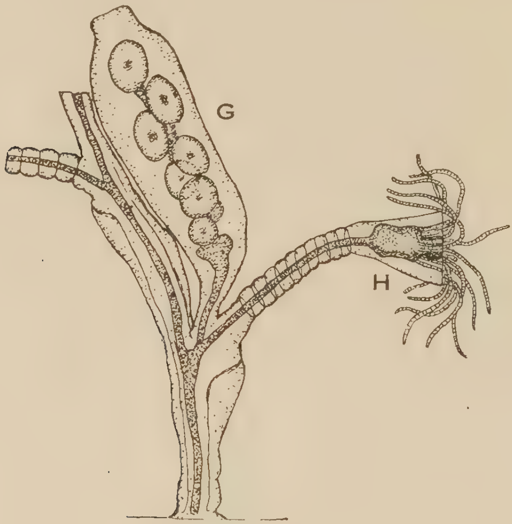


FIG. 179.—*Obelia*. G, gonosomes and gonotheca; H, hydranth and hydrotheca.

fertilized egg develops into a polyp. *Physalia pelagica*, the Portuguese man-of-war, is a free-swimming, colonial form, the individual, highly *polymorphic* members of which are in communication with one another by means of the common gastrovascular cavity. The colony is attached to a float (*pneumatophore*) containing gas that can be released through a pore, and later regenerated, enabling the animal to drop below the surface and rise again. There is an *alternation of generations*.

CLASS II. SCYPHOZOA. Radially symmetrical, with usually an alternation of generations, although the medusoid or the hydroid generation alone may be present in some. In general, the medusoid stage is more prominent in the group than the polyp. The latter, known as the *scyphistoma*, differs from Hydra in the following points: (1) the attachment of its *aboral* end in a cup; (2) the presence of four endodermal *mesenteries* projecting into gastrovascular cavity; (3) the possession of an ecto-

dermal *gullet.* The medusae are *acraspedote* (lacking a velum), and are produced from the scyphistome by terminal budding (*strobilization*).

Example: Aurelia, a large jellyfish, common on the Atlantic coast.

CLASS III. ANTHOZOA. Includes *sea anemones* and *corals*, possess only a *polyp* stage. The body is cylindrical and attached at the aboral end by the foot or pedal disc. The mouth is oval, giving the animal a

FIG. 180.—*Physalia*, the Portuguese Man-of-war, a pelagic colonial hydrozoan. *cr*, crest; *p*, polyp; *pn*, pneumatopore. (*From Parker and Haswell, Textbook of Zoology, copyright, The Macmillan Co. By permission.*)

bilateral symmetry, and is surrounded by from six to several hundred tentacles. An ectodermal *gullet* leads from the mouth to the gastrovascular cavity, which is subdivided by six or more longitudinal *mesenteries* composed of mesoglœa and endoderm. The ectoderm secretes, in corals, a *skeleton* of calcium carbonate, and in other forms a horn-like substance called *ceratine*. All are marine and the sexes are separate.

Examples: Cerianthus americanus, an Atlantic coast sea anemone; *Epizoanthus americanus,* a sea anemone often attached to a hermit crab; *Porites,* a common West Indian coral.

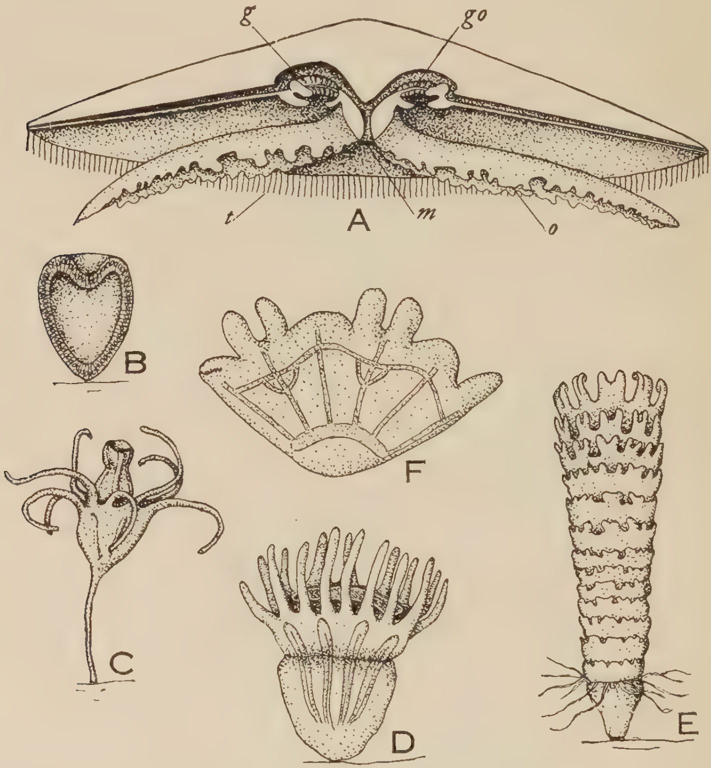


FIG. 181.—*Aurelia,* a jellyfish, and stages in the life history. A, vertical section of adult; B, vertical section of gastrula; C, polypiform larva with eight tentacles; D, scyphistoma with sixteen tentacles, in beginning of strobilation; E, strobila; F, ephyra, which develops into a jelly fish. g, gastral cavity; go, gonad; m, mouth, o, oral lobe; t, tentacles. (*After Leuckart-Nitsche wall chart.*

PHYLUM IV—CTENOPHORA

These beautiful marine animals are sometimes included in the *Cœlenterata,* which they resemble very closely. The *bilaterally symmetrical* body is almost transparent and may be round, oval, or ribbon-like in outline. Its outer surface is soft and bears eight longitudinal rows of *combs* whose teeth are composed of transverse plates of fused cilia. Ctenophore means comb-bearing. In many, branched *retractile tentacles* arise from pits near the

aboral pole. They are provided with *adhesive cells,* which are used in capturing prey. The slit-shaped *mouth* opens into a widened *stomach* region, to which are connected a system of tubes opening to the outside by minute pores. This complicated gastrovascular space is lined with endoderm. Between the latter and the ectoderm is a thick jelly-like mesenchyme, which differs from the mesoglœa of cœlenterates in that it represents a true third germ layer. The animals, therefore, are *triploblastic.*

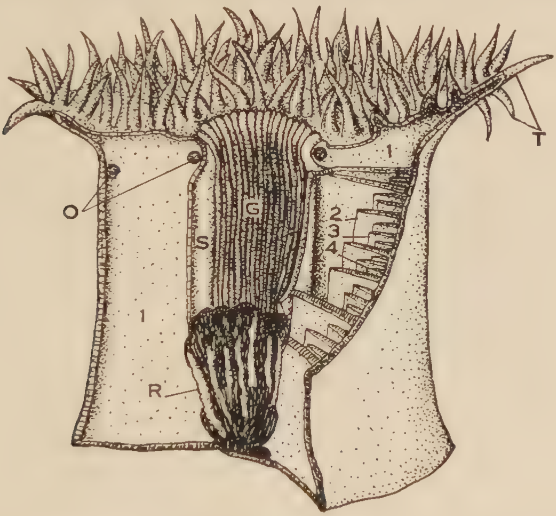


FIG. 182.—Dissection of *Metridium marginatum,* a sea anemone, showing the internal structure. 1, 2, 3, 4, primary, secondary, tertiary and quaternary mesenteries extending inward from the body wall, only the primary reaching the gullet, G. The gullet opens into a common basal gastrovascular cavity. O, ostia, pores through which water passes from one chamber to the other through the primary mesenteries. R, reproductive organs; S, scyphonoglyphe, a ciliated groove in either side of the gullet; T, tentacles. (*Modified from Linville and Kelly, Textbook in General Zoology, Ginn and Company.*)

Lying in a pit at the aboral pole is a *statocyst.*

Ctenophores are *hermaphroditic,* and pass through a complicated *metamorphosis* before reaching the adult stage.

The group is divided into two classes as follows:

CLASS I. TENTACULATA. Characterized by a pair of long *tentacles,* which, however, may appear only in the larva.

Examples: Pleurobrachia, sea comb; *Cestus veneris,* a flattened, ribbon-like form.

CLASS II. NUDA. *Tentacles absent.*

Example: Beroe.

PHYLUM V—PLATYHELMINTHES

Platyhelminthes (flatworms) are *bilaterally symmetrical, triploblastic* animals that never form fixed colonies by budding. The outer surface of the body is *ciliated* in the free-living forms. The alimentary canal when present is blind, like that of cœlenterates. Filling the space between the body wall and the internal organs is a loose connective tissue, called *parenchyma,* derived from the third germ layer. The nervous system consists of a *paired*

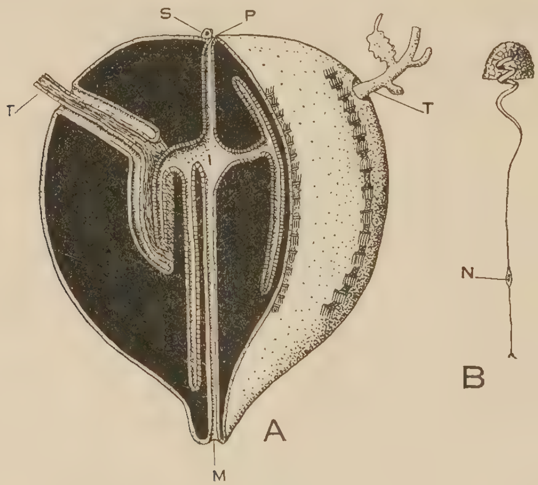


FIG. 183.—A diagrammatic dissection of *Hormiphora,* a ctenophore, the ectoderm is dotted, the endoderm striated, and the mesoderm solid black. I, infundibulum, the stomach region, which is connected with eight meridional canals one of which is shown beneath the more central row of combs. The infundibulum also gives off two stomodæal canals and two tentacular canals, one of each being shown in the figure. The stomodæal canal is close to the stomocæum, the tube leading from the mouth (M) to the infundibulum. P, excretory pore; S, statocyst; T, tentacle, the one on the left, in longitudinal section, shows the muscular core by which the tentacle may be retracted into the sheath. (*Based on Parker and Haswell.*) B, adhesive cell from a tentacle. The convex surface is sticky, and the coiled filament acts as a spring to prevent the cell being pulled out when it is attached to prey. The spiral thread is attached at its base to the muscular axis of the tentacle. N, nucleus. (*After Hertwig and Chun.*)

cerebral ganglion and peripheral *nerves.* In some members of the group, sense organs, in the shape of *eyes, tentacles,* and *statocysts,* occur. The excretory system consists of *flame cells* and protonephridial tubules. Reproduction is *sexual,* but *fission* and *budding* are also common. *Hermaphroditism* is the rule. The ovaries and testes are well-developed internal organs.

Many of the flatworms are *parasites* and their life histories are in many cases highly complex, as will be seen from the examples given below in the outline of classification.

CLASS I. TURBELLARIA. So called from the little currents (*turbella*) produced by the *ciliated ectoderm.* They are *free-living* in water or moist earth. The mouth is usually near the middle of the ventral surface of the body and opens into a muscular *pharynx* which can be thrust out of the mouth like a proboscis. *Nettle cells* are sometimes found.

SUBCLASS 1. ACŒLA. No intestine is present and usually no eyes. There is a statocyst in the dorsal surface near the cerebral ganglion. *Example: Childia spinosa*, marine form; 1.4 millimeter in length.

SUBCLASS 2. CŒLATA. An intestine is present.

Order 1. **Rhabdocœlida.** Intestine is a simple tube. Some reproduce asexually by terminal budding.
Examples: Dalyellia, common fresh water form; *Microstomum*, illustrates terminal budding.

Order 2. **Tricladida.** The intestine has *three* main branches with many small branches. There is a pair of eyes and tentacles at or near the forward end.
Example: Planaria maculata, fresh-water form.

Order 3. **Polycladida.** The intestine has *many* branches. Eyes, otocysts, tentacles, and tactile organs are well developed. Exclusively marine.
Example: Planocera inquilina occurs as a *commensal* inhabiting the branchial chamber of a large marine snail, *Busycon.*

CLASS II. TREMATODES. Exclusively *parasitic* and commonly known as *flukes.* Cilia are absent or present only in larval stages. The mouth is subterminal and the intestine is bifurcated. *Hooks* and *suckers* are found in *ectoparasites* for attachment to the host, but *suckers* only in *endoparasites.* The name of the class, Trematodes, refers to the presence of suckers (*trema*, hole). *Eye spots* occur in ectoparasites, but only in the larva of endoparasites.

Order 1. **Monogenea.** For the most part are *ectoparasites* on aquatic animals, but some change to endoparasitism. There is but *one host.* The organs for attachment, at the ends of the body, are well developed.
Examples: Tristoma coccineum, parasitic on the gills of the swordfish; *Polystoma*, as a *larva*, parasitizes the gills of the frog tadpole, but when the gills are absorbed at *metamorphosis*, it passes into the pharynx, through the alimentary canal to the urinary bladder, where it is found in the adult frog as an internal parasite.

Order 2. **Digenea.** *Endoparasites* living in two or more hosts, to which they attach themselves by one or two median suckers. *Fasciola hepatica*, the *liver fluke*, lives as an adult in the liver of sheep, where sexual reproduction takes place. The young embryos pass down the bile duct into the intestine, and out of the sheep's body into water, where they develop into a ciliated *miracidium*

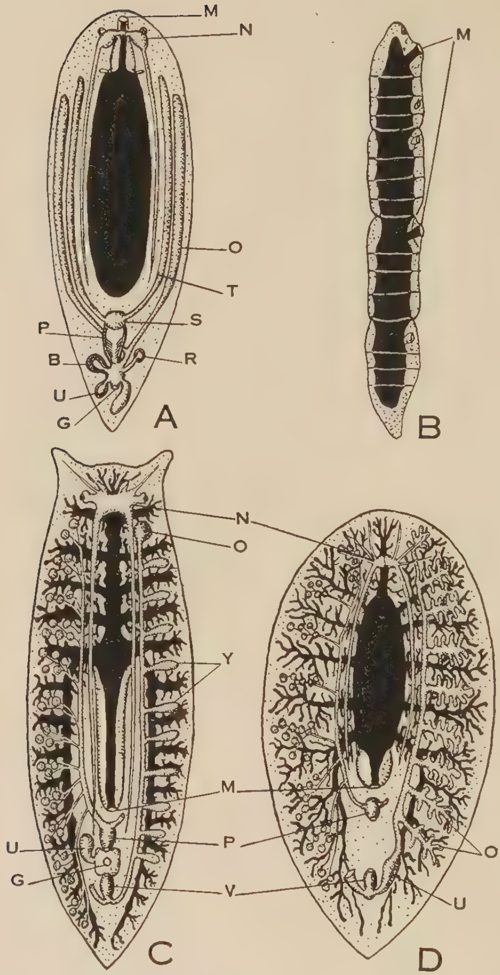


FIG. 184.—Types of Turbellarians, based on von Graff. A and B, Rhabdocœles; C, triclad; D, polyclad. The alimentary canal is represented in solid black. B shows strobilization or division taking place in a chain of four individuals of *Microstomum*. Division begins in the alimentary canal by the formation of septa which reach to the body wall. The chain really consists of sixteen partially formed zoöids. B, bursa copulatrix; G, genital aperture; M, mouth; N, nervous system; O, ovary; P, penis; R, receptaculum seminis; S, vesicula seminalis; T, testis; U, uterus; V, vagina; Y, yolk glands; in C and D the testis and its ducts are shown on the left side of the animal and the ovary and oviduct on the right.

larva. Its intermediate host is a water snail of the genus *Limnea*, whose tissues it enters by boring, and inside of which it forms a *sporocyst*. Eggs contained in the sporocyst develop parathenogenetically into *rediae*, which leave the sporocyst and enter the tissues. A number of parthenogenetic redia generations may be produced, followed, finally, by different larvae

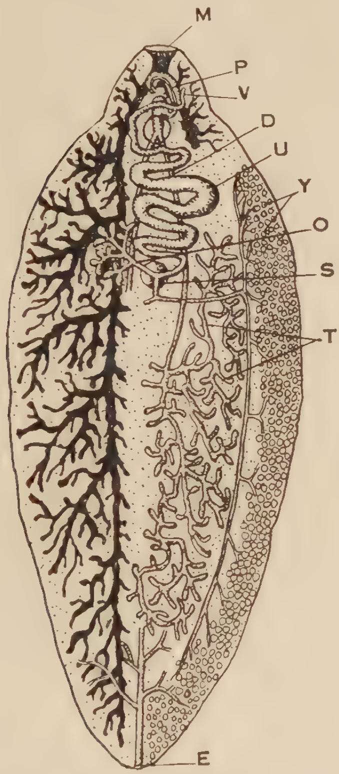


FIG. 185.—*Fasciola hepatica*, diagrammatic from the ventral side. The digestive tract in solid black is shown only in the left of the figure. The reproductive system is complete only in the right side of the figure. D, sperm duct; E, excretory pore and a small portion of the terminal excretory tubes: M, mouth; O, ovary; P, penis; S, shell gland; T, testis; U, uterus; V, vagina; Y, yolk glands. The ventral sucker is indicated by a circle below the penis.

known as *cercariae*. These resemble the adult, except that they have a tail, which serves as an organ of locomotion until the animal encysts on a water plant, when the tail is lost. Sheep are infected by eating plants bearing cysts, the contents of which find their way to the liver, where the young animals grow to maturity. Liver rot, the disease produced by this parasite, is often fatal. (Fig. 186.)

CLASS III. CESTODES. The tapeworms (*kestos*, girdle), are *endoparasites* having two body regions: (1) the *scolex*, or head, containing hooks or suckers for attachment to the host; (2) the *strobila*, which is a series of segments, called *proglottids*, each of which is provided with both male and female reproductive organs. Tapeworms inhabit the intestine of vertebrates and live as larvae in the tissues of another animal used as food by the *principal host*. There is no digestive tract, nutrition being

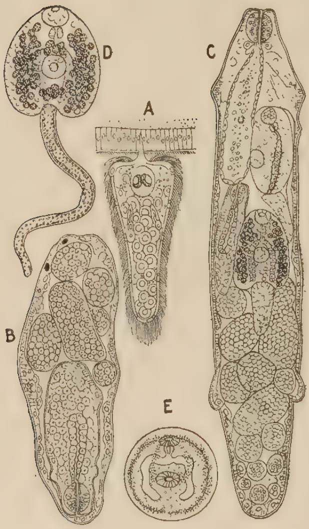


FIG. 186.

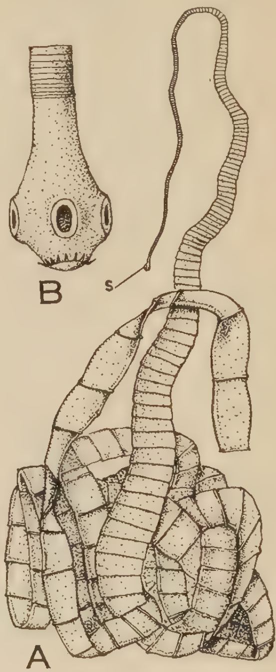


FIG. 187.

FIG. 186.—Stages in the development of *Fasciola hepatica*. A, miracidium; B, sporocyst; with rediae developing internally; C, rediae with second generation of rediae and cercariae; D, free cercaria; E, encysted cercaria. (*From Van Cleave, Invertebrate Zoology, after Thomas.*)

FIG. 187.—A, *Tænia solium*, the pork tapeworm. S, scolex. B, scolex, magnified. (*After Leuckart-Nitsche wall chart.*)

absorbed through the body wall. The outer covering is a *non-ciliated* cuticle capable of resisting the action of digestive juices. As the proglottids mature, they break from the chain. *Tænia solium*, the pork tapeworm, is found as an adult in the human intestine, where it reaches a length of from 4 to 10 meters. It attaches itself by means of hooks and suckers. A small *six-hooked larva* develops from the fertilized egg and is expelled. The larva must then enter the stomach of the pig, where it bores through the stomach wall, and finds its way to the skeletal muscles. Here the larva develops into an oval *cysticercus* (9 by 5 millimeters) and

remains as a cyst until the infected tissue is eaten by man. In the cavity of the cysticercus the scolex is developed in an inverted position, and when the cyst wall is dissolved by the gastric juice the scolex is protruded like

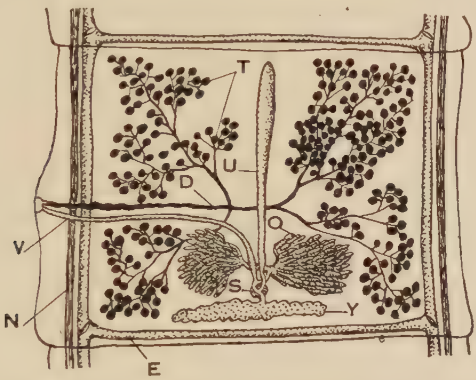


FIG. 188.—Diagram of a proglottid, showing organs of reproduction, based on Leuckart. D, sperm duct; E, excretory duct; N, nerve cord; O, ovary; S, shell gland; T, testis; U, uterus; V, vagina.

the finger of a glove. In the intestine the scolex attaches itself and develops proglottids from its posterior end. *Tænia saginata*, the beef tapeworm, has a similar life history, except that the intermediate host is the ox.

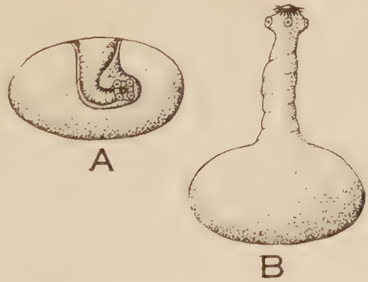


FIG. 189.—A, cysticercus (bladderworm) with inverted scolex. B, cysticercus with everted scolex. (*After Leuckart.*)

PHYLUM VI—NEMATHELMINTHES

The Nemathelminthes are the *roundworms* or threadworms (*nema*, thread), some of which are *free-living* in water or moist soil, while others are *parasitic* in animals and plants. The body is *unsegmented*, and lacks cilia and paired appendages. They are divided into three classes as follows:

CLASS I. NEMATODA. The mouth is terminal and the alimentary canal is a straight tube with an *anal* opening near the posterior end of the body. The body cavity lacks a peritoneal lining and is filled with blood (*hemocœl*). Four *longitudinal ridges*, one dorsal, one ventral, and two lateral, project into the body cavity. An *excretory canal* lies in each lateral ridge and opens on the surface at a common pore near the mouth. Surrounding the œsophagus is a *nerve ring*, containing ganglia, from which *nerve cords* pass back through the longitudinal ridges. Simple eyes and sensory papillae are present in some. The body covering is a smooth cuticula. Most roundworms are *parasitic.*

Trichinella spiralis, the cause of *trichinosis*, lives as an adult (male 1.5 millimeter in length, female 3 to 4 millimeters) in the small intestine of *man*, the *pig*, *rat*, *dog*, and *mouse*, where they reproduce sexually. The female after copulation penetrates the mucosa and gives birth to from 1,500 to 10,000 young. The latter migrate *via* the blood and lymph

FIG. 190.

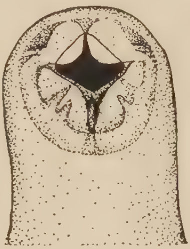


FIG. 191.

FIG. 190.—*Trichinella spiralis*, encysted in the muscle of the pig. (*After Leuckart.*)

FIG. 191.—Enlarged view of the dorsal side of the anterior end of the hookworm *Necator Americanus*, showing the quadrangular shaped mouth opening through which two of the flat, plate-like teeth can be seen. (*After Stiles.*)

to the muscles of the thorax, neck, and jaw, in which they become encysted, thereby injuring the muscles to such an extent that death of the host may ensue. Man is infected by eating undercooked pork containing cysts from which the young worms are liberated by the action of the gastric juice.

Necator americanus, the *American hookworm*, is found in the intestine of *man* and the *gorilla*, where it lives on the blood of its host, after first making a wound with its cutting lips and teeth. The adult male is 9 millimeters in length, and the female 11 millimeters. After copulation, the female deposits numerous eggs, which do not complete development until discharged with the feces. Development then proceeds, the embryo molting twice and remaining inside of the loosened skin after the second molt. There are two general modes of *infection:* (1) through the *mouth*, in which case the larva passes directly to the intestine; (2) through the *skin* of the feet and hands, from which it is carried by the blood to the lungs. Considerable damage is then caused by the animal boring through the lungs, heart, trachea, etc. to the intestine.

The hookworm is a serious menace in the South, especially in localities where precautions are not taken to avoid soil and water pollution.

Ascaris lumbricoides, an intestinal parasite, especially common in *children*. The male averages about 20 millimeters in length by 3 millimeters in diameter, and the female 30 by 5 millimeters. The eggs pass out with the feces and develop directly to the larval stages in water or moist soil. Infection is by mouth from water, soil, and the skin of raw fruits.

Fig. 192.

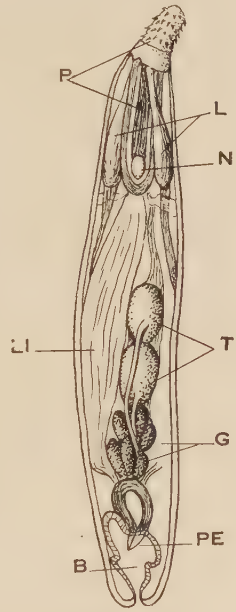


Fig. 193.

Fig. 192.—*Ascaris lumbricoides*, after Beneden. A, male ¾ nat. size; B, female, ¾ nat. size; c, head, enlarged, ventral side showing excretory pore; D, head, front view, three lobes surrounding the mouth; E, posterior end of the body of male greatly enlarged showing penial setae.

Fig. 193.—*Echinorynchus gigas*, male, after Leuckart. B, bursa; G, cement glands; L, lemnisci, two saccular organs of unknown function; LI, ligament; N, nerve ganglion; P, proboscis and sheath; PE, penis; T, testes.

CLASS II. GORDIACEA. The *hairworms*, occur in the adult state in water. The body cavity is lined with *peritoneum* and has dorsal and ventral *mesenteries*, but is nearly filled with a parenchymatous tissue. A pair of eyes and tactile bristles are present. The sexes are separate, and after fertilization the eggs are deposited in the water, where the larvae develop and parasitize aquatic insect larvae. When its host is eaten by a predaceous beetle, or if the host dies and the larva is eaten by a grasshopper, it develops to the adult stage in its second host, from which it makes its escape by breaking through the wall, eventually reaching water.

Example: Gordius, the horsehair worm.

CLASS III. ACANTHOCEPHALA. There are *three body regions:* (1) the *proboscis,* armed with hooks, (2) the *neck,* (3) the *trunk.* The proboscis contains a ganglion from which two nerve cords pass backward. There are no special sense organs. There is a body cavity, but no alimentary canal. A pair of nephridia opens into the reproductive duct. These animals are *parasitic* in the intestine of vertebrates, attaching themselves by the hooked proboscis. The larval stage is passed in an insect. Infection is by mouth from water containing the intermediate host.
Example: Echinorynchus anguillae, parasitic in fresh-water fishes.

PHYLUM VII—ROTIFERA

Rotifers are extremely small aquatic animals, discovered by Leeuwenhoek in 1703. There are *three body regions:* head, trunk, and tail. The head has a *ciliated disc* (corona), in the center of which is the mouth. The marginal cilia beat in opposite directions like revolving wheels. There is a *body cavity* and in some a *complete alimentary canal.* A pair of excretory tubes containing *flame cells* open into the hinder end of the canal. A supraœsophageal and sometimes a subœsophageal *ganglion* form the central nervous system. Eyes and tentacles may be present. *Sessile, colonial,* and *free-swimming* forms occur. The majority are found in fresh water, but some are marine.

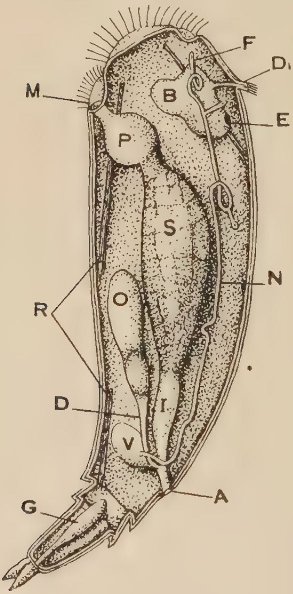


Fig. 194.—Diagram of a Rotifer. A, anus; B, brain; D, oviduct; DF, dorsal feeler; F, flame cell; G, cement gland; by the secretion of which the animal attaches itself temporarily; E, eyespot; I, intestine; M, mouth; N, nephridial tube; O, ovary; P, pharynx, containing masticating organs; R, retractor muscles; S, stomach; V, contractile vesicle (bladder). (*After Parker and Haswell.*)

Physiologically they show remarkable resistance to heat and drying, being capable of revival after years of desiccation if placed in water.

The *life history* of a typical rotifer is interesting. The fertilized *winter egg* has a thick shell for protection against cold and drought. In the spring it develops into a female, called the *stem mother.* The latter reproduces females parthenogenetically (*summer eggs*). The second generation of females may reproduce other females in the same way. After a time, however, the females thus produced are of two kinds: (1) *male-producing females,* and

(2) *female-producing females*, whose eggs develop into males and females respectively. The eggs of the latter are the winter eggs which are fertilized by the sperm of the male.

Whitney has found that feeding *Hydatina senta*, a common rotifer, with *Polystoma*, a colorless flagellate protozoan, results in the production of female-producing daughters; while feeding with *Chlamydomonas*, a green flagellate, causes only male-producing daughters to appear. It will be noted that the effect of diet appears in the second generation following feeding.

PHYLUM VIII—MOLLUSCOIDEA

Molluscoidea is a convenient, if not entirely satisfactory, term to include certain *mollusc-like* animals of uncertain position in the system of classification. The common feature of the members of the phylum is the presence of a *lophophore*, a tentacle-bearing ridge about the mouth. The other general characteristics of the two subdivisions of the group are briefly mentioned below.

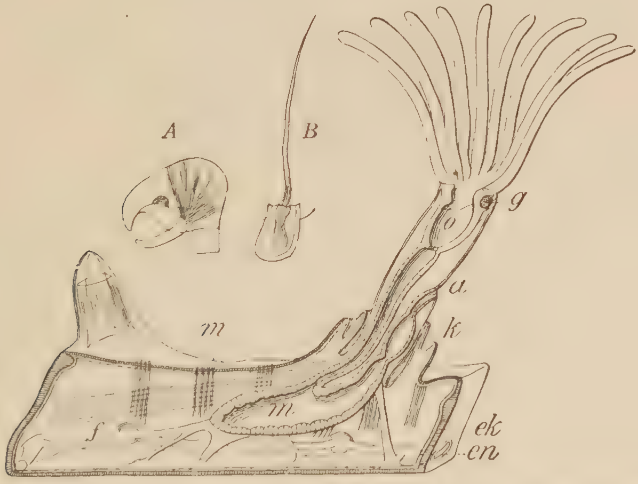


FIG. 195.—*Flustra membranacea* (*after Nitsche*), a single animal. *a*, anus; *ek*, ectocyst; *en*, entocyst; *f*, funiculus; *g*, ganglion; *k*, collar, which permits retraction; *m*, stomach; also dermomuscular sac; *o*, œsophagus; *A*, avicularium. *B*, vibracularium of *Bugula*. (*From Hertwig's Manual of Zoology by Kingsley. H. Holt and Co. After Claparede.*)

CLASS I. BRYOZOA. Very small *sessile* animals, usually *colonial*, and often forming a moss-like covering on rocks and plants in salt and fresh water. Externally, some of them bear a resemblance to compound hydroids, but internally the resemblance ceases, for the individual zoöids have a *body cavity* and a *complete alimentary canal*, bent so that the anus

lies near the mouth. There is usually a *central nervous system* between the mouth and the anus, and in some a pair of nephridia with *flame cells.* The *lophophore* is a horseshoe-shaped structure, encircling the mouth and bearing ciliated tentacles. Both *unisexual* and *hermaphroditic* forms occur. Bryozoa are very ancient animals, *fossils* having been found in the *Cambrian* and all subsequent formations.

Examples: Plumatella, a common fresh-water representative; *Flustra membranacea.*

CLASS II. BRACHIOPODA. Very important as *fossils,* extending from the *Cambrian* to the present time. There are 2,500 fossil species known, but only 120 living species (Pratt). A *bivalve* shell gives brachiopods a mollusc-like appearance, but the valves are *dorsal* and *ventral* instead of right and left, as in molluscs (p. 278). As a rule, the animal is attached by a muscular stalk, the *peduncle,* which is a prolongation of the

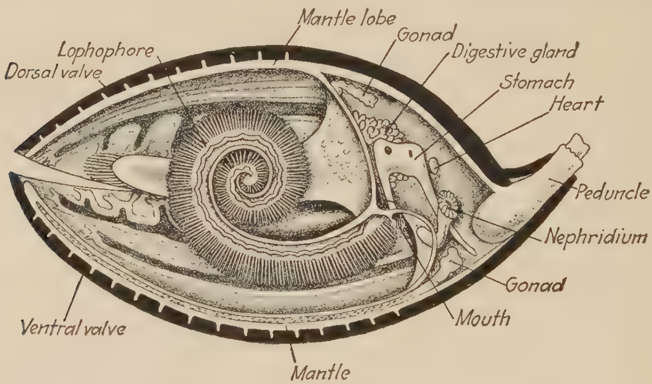


FIG. 196.—Semidiagrammatic sagittal section of a brachiopod, *Magellania lenticularis.* (*From Van Cleave, Invertebrate Zoology, after Parker and Haswell.*)

body. The *lophophores,* with ciliated tentacles, are coiled spiral arms, right and left of the mouth. The alimentary canal is usually *complete.* There is a *circulatory system* with heart and blood vessels. A pair of *nephridial tubes* connect the body cavity with the mantle cavity. The sexes are separate. The larval stage, *trochophore,* is similar to that of many annelids.

Examples: Lingula; Magellania lenticularis.

PHYLUM IX—ECHINODERMATA

Echinoderms are marine animals having a *radial symmetry* based on a *five-radiate* plan. The larva is *bilaterally* symmetrical, indicating that the radial symmetry of the adult is secondary. *Calcareous plates,* with or without spines, are developed in the mesoderm, and form a hard exoskeleton. An *ambulacral* water-vascular system is present. In the starfish this system

begins on the aboral surface with a porous plate, the *madreporite*, through which water enters a *stone canal* leading to a *ring canal* encircling the mouth. From the ring canal, five *radial canals* extend into the arms, and from each of these are given off at right angles paired *ambulacral canals*. Each of these, in turn, joins a tubular muscular sac, the *ambulacrum*, expanded at one end into an *ampulla*, and terminating in a *sucker disc* at its longer, free end, which can be extended or retracted through the ambulacral groove on the aboral surface of each arm. The system is filled with a fluid, mostly water, but containing lymph and blood corpuscles supplied by *glands* (Polian vesicles, Tiedemann bodies) attached to the system at various points. The

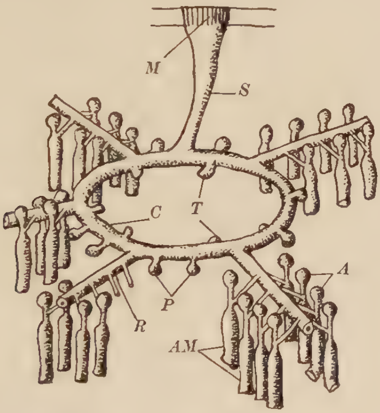


FIG. 197.—Water vascular system of the starfish, diagrammatic. A, ampulla; AM, ambulacra; C, ring canal; M. madreporite; P, polian bodies: R, radial canal; S, stone canal: T, Tiedemann bodies.

ambulacra are used in locomotion by extending and attaching the sucking discs to the substratum, a muscular contraction of the appendage then pulling the animal along. The ambulacra are also used in capturing and holding prey; they are important as *tactile organs*. In addition to the ambulacral system there is also a *blood circulatory system* in which blood is circulated by cilia lining the vessels.

The *five-radiate* symmetry is impressed on all of the internal organs. The *body cavity* is a complicated system of spaces, some of which are cut off from the rest, and all containing a fluid similar to that of the ambulacral system. The alimentary canal is usually a *complete tube* and lies in the largest of these spaces.

The nervous system consists of (1) a *superficial nerve ring* around the œsophagus, with *radial cords* extending into the arms; (2) a deeper *oral ring* and *radiating nerves;* (3) an *apical* system in the aboral wall but not present in all echinoderms. Respiration and excretion are carried on at the surface of the body, which is usually ciliated. Some starfish and brittle stars reproduce asexually by *fission,* but otherwise reproduction is *sexual.* The sexes are usually separate. While the eggs normally require fertilization, it has been found that they can be stimulated to develop by artificial means, *artificial parthenogenesis;* for this reason they have been favored material for experimental work along these lines. Ripe echinoderm eggs, when subjected to the effects of *hypertonic sea water,* certain *acids, temperature changes,* or *mechanical shock,* will develop without the intervention of a sperm.

Echinodermata are classified as follows:

CLASS I. ASTEROIDEA. The *starfishes* usually have five arms, with open *ambulacral grooves* on the adoral side, through which the ambulacra are extended. *Gastric pouches* and *hepatic cæca* extend into the arms. Spines and tubercles project on the surface. Starfish possess a remarkable power of regenerating lost parts.

Example: Asterius forbesi, a common starfish, Cape Cod region.

CLASS II. OPHIUROIDEA. The *brittle stars,* the arms of which are sharply set off from the central disc and are *without* ambulacral grooves. Hepatic cæca are *absent* and the intestine lacks an anal opening.

Example: Ophiura robusta, a Cape Cod form.

CLASS III. CRINOIDEA. The *sea lillies* and *feather stars* have a cup-shaped body, the *calyx,* attached by a *stalk* on its aboral side, at least in the early period of its development, if not in the adult. The oral surface is pointed upward, and contains the mouth, and also the anal opening. The arms are usually *branched* and *feathery* in appearance, and bear ambulacral grooves on the aboral surface. Crinoids were more abundant in *paleozoic* times than now, about 2,500 fossil species being known (Pratt).

Example: Antedon tenella, common on north Atlantic coast.

CLASS IV. ECHINOIDEA. A subglobular or disc-shaped body *without* arms. Usually, five *calcareous teeth* project from the mouth. The calcareous exoskeleton is well developed and is often provided with long *movable spines.*

Examples: Arbacia punctata, a sea urchin common on the Atlantic coast; *Echinarachnius parma,* the sand dollar.

CLASS V. HOLOTHURIOIDEA. An elongated, *worm-like shape,* with a *leathery integument,* the exoskeleton being much reduced. There is a partial bilateral symmetry. Regeneration is well marked.

Examples: Holothuria marmorata, trepang, used as food by the Chinese; *Cucumaria frondosa,* sea cucumber of the Maine coast.

PHYLUM X—ANNELIDA

Annelids are the *segmented worms;* the segmentation being both external and internal. The body wall is made up of an integument beneath which there are two layers of *muscle,* an outer circular and an inner longitudinal layer. *Paired appendages,* when present, are not jointed. A head region, the *prostomium,* contains the mouth, supraœsophageal nerve ganglion, and sense organs. The rest of the body is made up of similar *segments.* The nervous system is of the *ganglionic type,* consisting of a circumœsophageal nerve ring connecting ganglia above and below, and a ventral ganglionated nerve cord. The alimentary canal is *complete* and is surrounded by a *cœlomic space* subdivided into compartments by transverse *dissepiments.* Each segment contains a pair of *nephridial tubes.* There is a *blood circulatory system* of the open type, with contractile vessels.

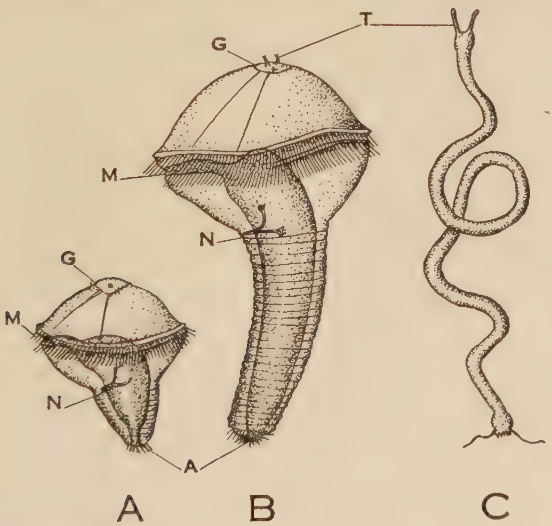


FIG. 198.—*Polygordius.* A and B, two stages in the development of the trochophore (trochosphere) larva which grows by the addition of segments to the posterior end. C, dorsal view of the adult. A, anus; G, rudimentary supraœsophageal ganglion; M, mouth; N, protonephridium, provided with flame cells; T, tentacles. (*After Hatschek and Fraipont.*)

Annelids are classified as follows:

CLASS I. ARCHIANNELIDA. Primitive marine forms *without setae* (locomotor bristles). A *trochophore-larva* stage occurs.

Example: Polygordius canaliculatus, common at Woods Hole.

CLASS II. CHÆTOPODA. Forms having *setae* arranged either in groups on the *parapodia,* or in *pits* in the integument.

Order 1. **Polychæta.** Provided with *parapodia*, which are fleshy extensions of the body wall, bearing numerous *setae.* The head is distinct and bears *eyes*, *tentacles*, and *cirri. External gills* are sometimes present. The sexes are separate, and in reproduction there is usually a *trochophore-larva* stage. The free-swimming forms burrow in the sand, which they only leave to capture food and for reproduction. Sedentary species live in permanent tubes made of a limy secretion. Most are marine.

Examples: Nereis virens, a free-swimming form, marine; *Chætopterus pergamentaceous,* lives in a U-shaped tube buried in the sand.

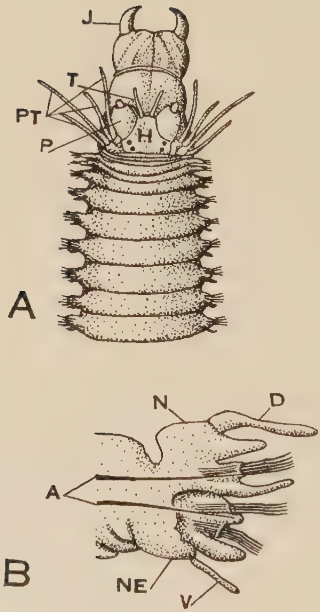


FIG. 199.

FIG. 200.

FIG. 199.—A, Anterior end of *Nereis* with proboscis extended. (*After Ehlers.*) B, enlarged view of parapodium from posterior aspect. (*After Quatrefages.*) A, acicula (large bristles embedded in parapodium); D, dorsal cirrus; H, head (præstomum) bearing four simple eyes; J, jaw; N, notopodium; NE, neuropodium; P, palp; PT, peristomal tentacles; T, tentacles; V, ventral neuropodium.

FIG. 200.—Diagram of alimentary canal of leach. A, anal opening; G, nerve ganglia; H, head with eyespots; P, muscular pharynx; S, stomach; SU, sucker.

Order 2. **Oligochæta.** Parapodia and cephalic appendages are *absent*. The head region consists of the *prostomium* and the *peristomium*, the latter containing the mouth. *Setae* are few in number and are arranged in clusters. Oligochaets are *hermaphroditic*, and development is *direct*. Most of them are fresh-water or terrestrial.

Example: Lumbricus terrestris, the earthworm.

CLASS III. HIRUDINEA. The *Leeches*, lack parapodia, tentacles, and setae, but have *sucking discs*, one surrounding the mouth and one at the posterior end of the body. The body is *flattened* dorsoventrally, and externally has *three* or more rings to a segment. The body cavity is partially filled with a vacuolated *parenchyma*. In some leeches there are three sharp *chitinous plates* in the pharynx that are used in drawing blood. In others a *proboscis* can be thrust out of the pharynx and used for the same purpose. In many the crop and the stomach have capacious *pouches*, which become greatly distended after a meal. *Eyes* and other *sense organs* are present at the head end. Leeches are *hermaphroditic* and development is *direct*. They are found principally in fresh water, though a few are marine and others occur in moist soil. They prey upon practically all aquatic animals.

Examples: Hirudo medicinalis, the *medicinal leech*, a European form used for blood letting; *Macrobdella decora*, one of the larger fresh-water leeches.

PHYLUM XI—ARTHROPODA

Arthropods, like annelids, are *segmented externally*, and the arrangement of the nervous system, muscles, heart, and other organs shows evidence of *internal segmentation*. On the other hand, arthropods differ from annelids in that (1) the segmentation is *heterononous*, which means that the primitive segments are fused to form larger segments, such as the *head*, *thorax*, and *abdomen*; (2) the paired appendages are *jointed;* (3) the *body cavity* is almost *eliminated*. The possession of jointed appendages is the most important feature and gives the name to the phylum; Arthropoda means jointed feet. These appendages were primarily *locomotor* in function, a function which some of them have retained, while others have evolved into (1) *antennae*, sense organs; (2) *mandibles* and *maxillae*, chewing organs; (3) *maxillipeds*, intermediate between legs and jaws; (4) *pleopods*, the *swimmerets* of crustacea; (5) *spinnerets*, the spinning organs of spiders; (6) the *ovipositor* of insects, etc.

The chitinous *exoskeleton* is a secretion of the epidermis and serves as a protective covering to which muscles and other organs are attached. The alimentary canal is a *complete* tube, highly differentiated into various regions. The muscular

system is well developed; all of the muscles are striated. The nervous system is of the *ganglionic type*, like that of annelids, but as a result of condensation, or concentration, the number of ganglia in the ventral chain is reduced and often does not correspond in number with the body segmentation. There are two types of eyes, simple *ocelli*, and *compound* eyes. Except in the small crustaceans, there is a blood circulatory system, but the degree of development of the vessels depends upon the character of the respiratory system. Thus, vessels are practically absent in forms that have a diffuse organ of respiration, like the tracheal system of insects, but are well developed in gill-breathers, like the crustaceans. The heart is tubular and

FIG. 201.—Appendages of crayfish of right side, ventral view, ¾ natural size. 1, first antenna; 2, mandible; 3, 4, first an dsecond maxillae; 5, 6, 7, maxillipeds; 8, pleopod; 9, first walking leg (biramous).

lies in the middorsal line. Both *nephridia* and *Malpighian tubules* occur as organs of excretion.

The eggs contain a large amount of yolk, which is enclosed in a thin layer of yolk-free cytoplasm. The union of the male and female nuclei takes place in the center of the yolk. Cleavage is of the *superficial* type which means that the yolk-free cytoplasm is organized into a blastoderm by the immigration of cleavage nuclei arising in the yolk. Hermaphroditism is rare. Alternation of amphigony with parthenogenesis (*heterogony*) is met and sometimes parthenogenetic reproduction in these cases takes place in the larval stage (*pædogenesis*). *Metamorphosis* is common.

Over 400,000 species of arthropods are known, which is four-fifths of the total number of known species of animals. An outline of the classification follows:

CLASS I. CRUSTACEA. Mostly *aquatic*, breathe by means of gills, have biramous appendages, and two pairs of antennae. The presence of large amounts of calcium carbonate in the exoskeleton makes it thick and hard, and gives the name to the group. The first two body regions are usually fused into a *cephalothorax*. Many of the smaller crustacea are parasitic. Barnacles are the only sessile forms.

SUBCLASS 1. ENTOMOSTRACA. These are small in size, with a variable number of segments. Head, thorax, and abdomen are distinct in some.
Examples: Branchipus vernalis, a fresh-water shrimp; *Daphnia pulex*, a fresh-water cladoceran; *Temora longicornis*, a copepod, marine; *Cyclops viridis*, a fresh-water copepod; *Cypris virens*, a fresh-water ostracod; *Balanus balanoides*, the rock barnacle.

SUBCLASS 2. MALACOSTRACA. Usually with twenty *body segments:* head five, thorax eight, and abdomen seven: and nineteen pairs of *appendages:* head five, thorax eight, and abdomen six. Head and thorax generally combined in a cephalothorax.
Examples: Porcellio scaber, a sow bug; terrestrial; *Palæmonetes vulgaris*, a common shrimp, marine; *Homarus americanus*, American lobster; *Cambarus*, American crayfish; *Cancer irroratus*, a common New England crab.

CLASS II. ARACHNOIDEA. *No* antennae are present. There are two body divisions, the cephalothorax, with six paired appendages, and the abdomen, *without* appendages, except in the horseshoe crab.

SUBCLASS 1. XIPHOSURA. A horseshoe-shaped cephalothorax, six plate-like paired appendages on the abdomen, and a spike-like tail.
Example: Limulus polyphemus, the American horseshoe crab.

SUBCLASS 2. ARACHNIDA. The cephalothorax bears six pairs of appendages: the mandibles or *chelicerae*, the *pedipalps*, and four pairs of walking legs. The last three pairs of abdominal appendages are modified into *spinnerets*. Mostly terrestrial and breathe by modified gills known as lungs.
Examples: Diplocentrotus whitei, a scorpion of the southwestern United States; *Argiope aurantia*, an orb-weaving spider (all spiders belong to the Arachnida); *Sarcoptes scabei*, one of the itch mites, causing itch in man and mange in pigs. *Margaropus annulatus*, the Texas cattle tick. The bite of the tick inoculates cattle with *Babesia bigemina*, a sporozoan which causes *Texas fever*.

CLASS III. TRACHEATA. A *tracheal* system of respiration and a distinct *head*, bearing a single pair of *antennae* characterizes this class.

Division 1. Onychophora. The head bears a pair of simple eyes, a pair of segmented antennae, and a mouth with a pair of hooked jaws. The worm-like trunk is *unsegmented* and provided with numerous annulated legs (fourteen to forty-three pairs). The body cavity is a hemocœl through which the alimentary canal passes as a straight tube. There is a pair of *nephridia* at the base of each pair of legs. The sexes are separate. In *viviparous* forms the egg is poor in yolk and is totally divided in cleavage. The embryo in such cases is nourished by the walls of the *uterus*, forming a very primitive sort of *placenta*. The animals are terrestrial and feed on insects and other small forms.

From the point of view of evolution, they are important as a connecting link between annelids and arthropods.

Example: Peripatus eiseni, a viviparous species; habitat, central South America.

Division 2. Myriapoda. The head bears a pair of segmented antennae, a pair of mandibles, and one or two pairs of maxillae. The trunk is segmented (11 to 173 segments) and each segment has *one* or *two pairs* of legs with claws. The sexes are separate and all are oviparous. Development is direct.

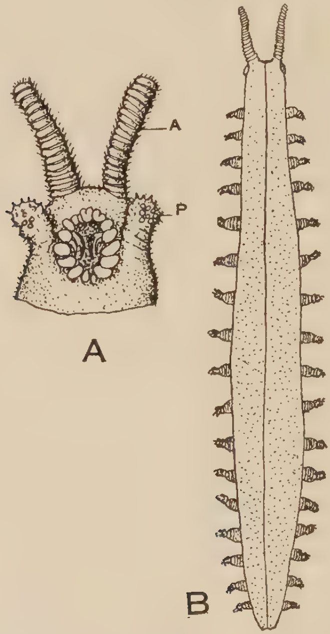


FIG. 202.—A, ventral view of the head of *Peripatus capensis*, showing the mouth surrounded by lips raised into large white papillae. B, dorsal view of entire animal. A, antenna; P, oral papilla at the base of which a gland ejects a sticky slime used in capturing food. (*After Leuckart-Nitsche wall chart.*)

Order 1. **Progneata.** A cylindrical body with usually two pairs of legs to a segment. A single pair of maxillae. An anterior genital pore.

Example: Julus virgatus, a common millepede.

Order 2. **Chilopoda.** A flattened body with *one pair* of legs to a segment. Two pairs of maxillae. The first pair of legs are maxillipeds, provided with *poison glands.* Reproductive openings are posterior.

Example: Scolopendra, a common southern centipede.

Division 3. Insecta. Insects have three body divisions: *head, thorax,* and *abdomen;* and *three pairs* of legs. The head bears four pairs of

appendages; antennae, mandibles, maxillae, and labium. The trunk is composed of three segments: *pro-*, *meso-*, and *meta- thorax*, each of which bears a pair of legs. The meso- and meta- thorax may each have a pair of *wings*. The reproductive organs open at the end of the body. The sexes are separate. A metamorphosis in development is common. Insects constitute the largest division of arthropods and are subdivided into many orders, of which those including the more common insects are given below.

Order **Aptera.** *Wingless:* body covered with scales or hair; development direct.
Example: Campodea, springtail.

Order **Orthoptera.** Anterior pair of wings are straight and narrow and cover the posterior membranous pair. Mouth parts for biting and chewing. Metamorphosis incomplete or absent. *Examples: Blatta,* cockroach; *Melanopus,* grasshopper; *Gryllus domesticus,* house cricket; *Diapheromera,* walking stick.

Order **Odonata.** Both pairs of wings membranous with marked veining, biting mouth parts, and practically complete metamorphosis.
Example: Anax junius, a common dragon fly.

Order **Hemiptera.** The *bugs, lice, scale insects.* Paired membranous wings, or none; sucking mouth parts; metamorphosis incomplete. *Examples: Anasa tristis,* squash bug; *Pediculus capitis,* head louse; *Aphis,* a plant louse (wingless); *Cicada,* sometimes called locust.

Order **Diptera.** A single pair of anterior wings (except in fleas), the posterior pair reduced or absent; mouth parts for piercing and sucking; metamorphosis complete.
Examples: Anopheles, malarial mosquito; *Glossina palpalis,* the tsetse fly, which carries the germs of *sleeping sickness; Musca domestica,* house fly; *Cecidomyia destructor,* Hessian fly.

Order **Lepidoptera.** *Butterflies* and *moths.* Two pairs of membranous wings covered with scales; sucking mouth parts; complete metamorphosis. The adult are short-lived and some do not eat at all.
Examples: Pieris rapae, the cabbage butterfly; *Porthetria dispar,* the gypsy moth, the larva of which is especially destructive to foliage; *Bombyx mori,* the silkworm moth.

Order **Coleoptera.** The *beetles.* The anterior wings (*elytra*) serve as covers for the posterior membranous pair; mouth parts for biting and chewing; metamorphosis complete.
Example: Photinus pyralis, firefly. *Leptinotarsa decemlineata,* the potato bettle, the larva of which feeds on the leaves of the potato plant.

Order **Hymenoptera.** Bees, wasps, gallflies, and ants. Two pairs of membranous wings; mouth parts for sucking and biting; metamorphosis complete.
Examples: Apis mellifica, the honey bee; *Rhodites rosae,* gallfly; *Vespa,* paper-nest wasp, the yellow jacket; *Formica,* an ant.

PHYLUM XII—MOLLUSCA

Molluscs are *soft-bodied, bilaterally symmetrical, unsegmented* animals, with only a remnant of a cœlom, and usually enclosed in a *shell.* In well-developed molluscs, like the snail, four body parts can be distinguished: (1) the *visceral sac,* containing the viscera and forming the bulk of the body. This is continuous in front with (2) the *head,* bearing the mouth, tentacles, and eyes. (3) The *foot,* the organ of locomotion, lies ventral to the visceral sac. (4) The *pallium,* or *mantle,* is a dermal fold, forming between it and the sac a mantle cavity which is provided with gills or lungs, and receives the openings of the intestine, reproductive ducts, and excretory organs. The outer surface of the mantle secretes the shell.

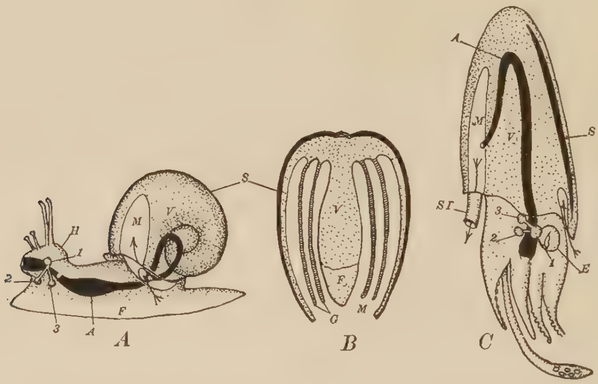


FIG. 203.—Diagrams of three types of molluscs. A, Gasteropod; B, Lamellibranchiate, cross section; C, Cephalopod. A, alimentary tract; E, eye; F, foot; G, gills; H, head; M, mantle cavity; S, shell; SI, siphon; V, visceral mass; 1, cerebral ganglion; 2, pedal ganglion; 3, visceral ganglion.

The *nervous system,* typically, consists of three pairs of ganglia connected by cords: (1) The *cerebral ganglia* lie dorsal to the œsophagus and supply the sense organs of the head. (2) The *pedal ganglia* lie in the foot, and supply statocysts and muscle. (3) The *visceral ganglia* lie in the viscera, which they supply, and also send nerves to the *osphradia,* organs of chemical sense located in the mantle cavity.

The mouth opens into a muscular pharynx, usually provided with a *radula,* a toothed, chitinous ribbon, used for rasping. Attached to the stomach is a large liver. Paired or single *nephridial tubules* drain the *pericardium,* which represents the

cœlom, and open into the mantle cavity. The circulatory system is composed of a heart with a *ventricle* and one or two *auricles*, arteries, and veins. The ventricle drives the blood through the arteries to the tissues, lacunar spaces, from which veins take it to the kidneys and gills, and then to the heart. The blood in the heart is, therefore, always pure. Both unisexual and hermaphroditic forms occur. A *veliger-larva* stage is common in development.

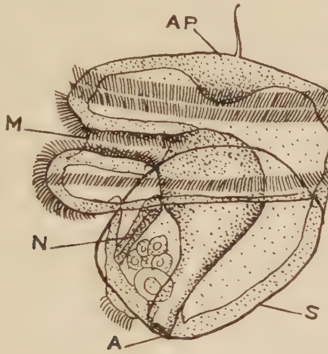


FIG. 204.—Veliger-larva of *Toredo*. (*After Hatchek.*) A, anus; AP, apical plate bearing a cilum; M, mouth; N, nephridial tube; S, shell. (Compare with Fig. 198.)

Molluscs are classified as follows:

CLASS I. AMPHINEURA. The nervous system consists of an œsophageal ring and four longitudinal nerve cords. Those without a shell are wormlike in appearance. A radula is usually present. All are marine.
Examples: Chiton, rock sucker; *Chætoderma* (no shell).

CLASS II. SCAPHOPODA. Have *tubular shells.* A radula is present. Sexes are separate. All marine.
Example: Dentalium entale, tooth shell.

CLASS III. GASTEROPODA. *Snails* and *slugs.* Asymmetrical body with four parts well developed; a creeping foot; an unpaired mantle, nephridium, and gonad. The shell is usually coiled spirally. A radula is present. Aquatic forms breathe by gills, the land forms with lungs.
Examples: Lymnea palustris, a fresh-water snail; *Busycon carica,* conch, marine; *Helix pomatia,* French snail, edible; *Limax flavus,* a slug (no shell).

CLASS IV. PELECYPODA. Lack a head and cephalic appendages. Have a *bivalve shell* consisting of right and left halves; with paired mantle, gills, nephridia, and gonads. Frequently the hinder edges of the mantle are modified to form incurrent and excurrent *siphons.* The sense organs are poorly developed. Sexes are separate usually.

Examples: Anodonta grandis, a fresh-water clam; *Ostrea virginica*, the American oyster; *Venus mercaneria*, the hard-shelled clam; *Mya arenaria*, the soft-shelled clam.

CLASS V. CEPHALOPODA. Active, carnivorous, marine forms, including the largest and most highly organized molluscs. As a rule, eight or ten *tentacles* surround the mouth, and with the *siphon* represent the foot region. A pair of sharp *chitinous jaws* lie just back of the lips in the mouth. The siphon is an excurrent tube from the mantle cavity. The mantle is unpaired. A shell may be present or not. The highly developed paired *eyes* strongly resemble those of vertebrates. *Statocysts* and *osphradia* are also present. Except in *Nautilus*, there is a glandular *ink sac* opening near the end of the rectum, which secretes a brown or black fluid. The ink is expelled from the mantle cavity through the siphon and affords protection by clouding the water. The sexes are separate.

Examples: Loligo peali, the common squid, its shell (cuttlebone) being embedded in the tissues; *Octopus bairdi*, devil fish (no shell); *Nautilus pompilius*, pearly nautilus, which has a shell divided into compartments.

PHYLUM XIII—CHORDATA

Chordates are characterized by (1) the presence of a *notochord*, a smooth, elastic rod lying between the nervous system and the

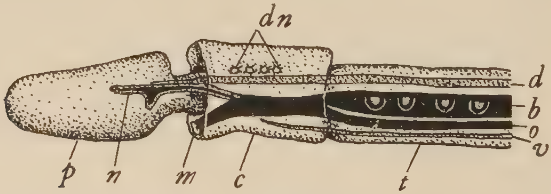


FIG. 205.—Diagram of the anterior end of *Balanoglossus*. *b*, branchial region of alimentary tract with gill clefts; *c*, collar; *d*, dorsal blood vessel; *dn*, dorsal nervous system; *m*, mouth; *n*, notochord consisting of a tube of cells connected with the alimentary canal; *p*, proboscis; *t*, trunk; *v*, ventral blood vessel.

digestive tract; (2) a *tubular central nervous system*, which, with one exception, *Enteropneusta*, lies dorsal to the digestive tract; (3) a pharynx with *gill slits*, which may or may not be functional as respiratory organs in the embryo or adult.

SUBPHYLUM I. ENTEROPNEUSTA. Unsegmented worm-like animals with three body divisions: (1) *proboscis*, (2) *collar*, and (3) *trunk*. A blind tubular extension from the pharynx into the proboscis is taken to represent the notochord. The nervous system consists of (1) a dorsal portion lying in the collar, and (2) a ventral portion lying in the ventral ectoderm of the trunk and connected with the dorsal part by a nerve ring just behind the collar. The dorsal portion develops from a tube, as in vertebrates. The mouth lies ventral and in front of the collar. The pharynx, per-

forated with gill slits, leads to the intestine, which terminates in an anus at the posterior end of the body. Dorsal and ventral mesenteries support the intestine and divide the coelomic cavity into two pouches. There are dorsal and ventral blood vessels, a portion of the dorsal one being contractile. Are all marine.

Example: Balanoglossus aurantiacus.

SUBPHYLUM II. TUNICATA. The presence in many tunicates of a *mantle cavity*, with incurrent and excurrent siphons, gives them a superficial resemblance to molluscs. The mantle is covered by a *tunic* composed largely of *cellulose.* The *incurrent opening* is the mouth, which leads to the wide pharynx through whose gill slits the water passes either directly to the outside, or into a peribranchial or cloacal space, which opens to the outside by the *excurrent syphon.* In the midventral line of the pharynx is the *endostyle,* a glandular ciliated groove, whose cilia move entangled food masses forward to the ciliated *peripharyngeal band,* from which it passes to the *dorsal lamina,* another ciliate tract in the middorsal line, whence it reaches the œsophagus. The latter is followed by a stomach and intestine, the intestine opening into the cloacal cavity. The heart has the peculiar property of periodically *reversing* the direction of its beat, driving the blood toward the gills for a certain interval and then driving it in the opposite direction to the viscera, etc. The central nervous system develops from a tube and is entirely dorsal to the alimentary canal. In *Salpa* there is an alternation of generation between a solitary asexual form and a sexual chain form. Tunicates are generally *hermaphroditic.* All are marine.

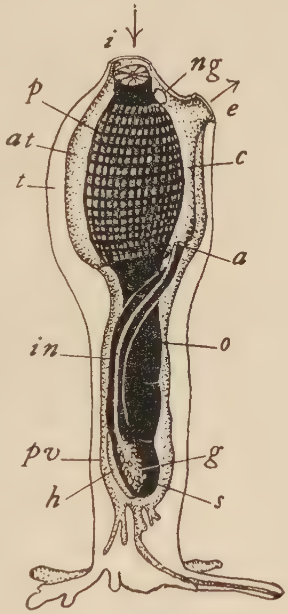


FIG. 206.—Diagram of a Tunicate, one-half of the tunic removed. *a,* anus; *at,* atrium; *c,* cloaca; *e,* excurrent siphon; *g,* gonad whose duct following the intestine opens into the cloaca; *h,* heart; *i,* incurrent siphon; *in,* intestine; *ng,* nerve ganglion; *o,* œsophagus; *p,* pharynx; *pv,* perivisceral cavity; *s,* stomach; *t,* tunic. (*Based on Leuckart-Nitsche wall chart.*)

Examples: Ciona intestinalis, sea squirt, a sessile form; *Salpa,* a pelagic form.

SUBPHYLUM III. CEPHALOCHORDA. Fish-like, *free-swimming* animals, in which the *notochord* extends the length of the body. The musculature of the trunk is conspicuously segmented into *somites.* There is no heart, auditory organ, skull, or vertebral column. The brain is little more than the expanded anterior end of the neural tube. A *median olfactory pit* lies at the anterior end of the brain. The pharynx is provided with gill slits opening externally into a *peribranchial chamber* from which the water leaves by a median pore caudad. There is a dorsal and ventral blood vessel, connected by loops.

The anterior end of the ventral trunk and parts of other vessels are contractile. Above the upper ends of the gills slits are numerous nephridial tubes which open into the atrium or peribranchial chamber. The sexes are separate. All are marine.

Example: Amphioxus, the lancelet, lies buried in the sand up to the mouth, in an upright position, in shallow water.

SUBPHYLUM IV. VERTEBRATA. The notochord is the *body axis* of the embryo, but is replaced in varying degrees in the adult by the *centra* of the vertebral column. *Segmentation* is indicated by the metameric arrangement of muscles, nerves, and vertebrae. The body cavity is a *cælom* in which the intestine is suspended by a dorsal mesentery. There are two kinds of appendages supported by internal skeleton: (1) *unpaired median fins* (fishes), and (2) *paired appendages* (anterior and posterior fins, or arms and legs). The central nervous system is tubular and entirely dorsal to the alimentary canal. The anterior end of the neural tube is enlarged into a *brain* composed of five regions: (1) *telencephalon*, (2) *diencephalon*, (3) *mesencephalon*, (4) *metencephalon*, and (5) *myelencephalon;* the remainder of the neural tube forms the *spinal cord*. *Eyes* and *ears* are highly developed. The organs of respiration, *gills* or *lungs*, arise (except in some *Amphibia*) from the endoderm of the pharynx. Gill slits are a constant feature of the embryo. The circulatory system is highly developed and of the closed type. Hermaphroditism is rare.

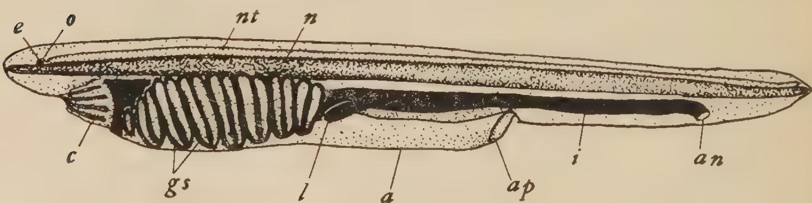


FIG. 207.—Diagram of young *Amphioxus* shortly after metamorphosis. a, atrium; *an*, anus, opening asymmetrically on the left side; *ap*, atriopore; *c*, oral cirri, surrounding mouth; *e*, eyespot; *gs*, gill septa; *i*, intestine; *l*, liver; *n*, notochord; *nt*, neural tube. (*Based on Leuckart-Nitsche wall chart.*)

CLASS I. CYCLOSTOMATA. Rudimentary cartilaginous neural arches may develop, but the *notochord* persists as the skeletal axis of the adult. No paired appendages, scales, true teeth, or jaws. The mouth lies at the bottom of a *suctorial funnel* lined with sharp, cuticular spines, by means of which the animal fastens itself to fishes. The end of the tongue, armed with similar spines, can be extended through the mouth and is used as a rasping organ. In respiration water does not enter the mouth but is pumped in and out through tubular gill clefts. The olfactory organ is median and unpaired. The *hypophysis* opens anteriorly into the nasal sac. The heart has one auricle and one ventricle.

Examples: Myxine glutinosa, the *hagfish*, actually bores into its prey, which it completely devours from the inside. It is marine, and protandric hermaphroditic (*i.e.*, it is male and female alternately). The hypophysis opens posteriorly into the oral cavity. *Petro-*

myzon marinus, the sea lamprey, feeds on mucus and blood rasped from fishes. The hypophysis has no connection with the oral cavity.

CLASS II. ELASMOBRANCHII. The *sharks* and *rays,* are characterized by a *cartilaginous skeleton* in which the notochord is only partially replaced by the centra of the vertebra; a skull with *jaws;* a *subterminal* mouth (ventral); paired and median fins; a spiral valve in the intestine; a *heterocercal* tail. Scales are present and of the *placoid type,* which is the forerunner of the mammalian tooth. There is no swim bladder. All are marine.

Examples: Squalus, a common dogfish; *Raia,* ray.

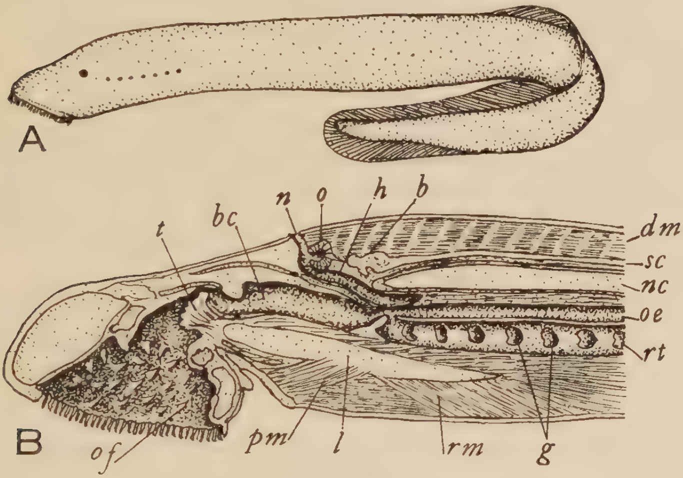


FIG. 208.—A, *Petromyzon marinus.* B, median section of anterior end of body. *b,* brain; *bc,* buccal cavity; *dm,* dorsal musculature; *g,* internal openings of gill pouches; *l,* lingual cartilage; *n,* nasal opening; *nc,* notochord; *o,* olfactory sac; *oe,* œsophagus; *of,* oral funnel; *pm,* protractor muscle of tongue; *ps,* pituitary sac; *rm,* retractor muscle of tongue; *rt,* respiratory tract; *sc,* spinal cord; *t,* tongue.

CLASS III. PISCES. A more or less *ossified skeleton* is present; *scales,* when present, are never of the placoid type; the five gills slits are covered externally with a bony *operculum*; there is usually a *swim bladder.*

SUBCLASS 1. TELEOSTOMI. Breathe by gills, and the skeleton is usually bony. Includes the familiar fishes: cod, salmon, perch, etc.

SUBCLASS 2. DIPNOI. The *lung fishes,* have a single or paired swim bladder functioning as a *lung,* although gills are also present. The skeleton is partially ossified cartilage.

Example: Protopterus, the African lung fish, a fresh-water form, at times of drought burrows into the mud and forms a *cocoon,* remaining in a state of suspended animation until the return of the rainy season.

CLASS IV. AMPHIBIA. Usually have *paired appendages* of the *pentadactyl* type. Scales are absent except in *cæcilians* and fossils; gills are usually lost in the adult; *lungs* are present except in lungless salamanders; the heart has two auricles and one ventricle. None is marine.

Order 1. **Apoda.** Blind burrowing forms without limbs, covered with scales. Exclusively tropical.
Example: Cœcilia.

Order 2. **Caudata** (*Urodela*). A well-developed tail; gills permanent in some, lost in others.
Examples: Necturus, the *mud-puppy,* has persistent external gills; *Crytobranchus,* the hellbender, has internal gills; *Amblystoma,* a common salamander, has only lungs; *Eurycea,* the lungless salamander has neither gills nor lungs and breathes through the skin.

Order 3. **Salientia** (*Anura*). A tail is absent, the caudal vertebrae being reduced to a *urostyle;* the posterior appendages are modified for leaping; the *metamorphosis* is marked.
Examples: Rana, common frog; *Bufo,* toad.

CLASS IV. **REPTILIA.** The skeleton is strongly *ossified;* the body is covered with *epidermal scales,* or *ossified dermal plates;* breathe with *lungs* (no gill respiration); the heart has two auricles and two incompletely separated ventricles.

Order 1. **Testudinata.** *Turtles.* The trunk enclosed in a bony capsule, the *carapace* above and the *plastron* below; the jaws are provided with *horny plates* instead of teeth.

Order 2. **Squamata.** *Snakes* and *lizards.* A covering of horny epidermal scales periodically renewed. Snakes have no limbs.

Order 3. **Crocodilina.** *Alligators* and *crocodiles. Bony plates* in the skin; teeth in separate *sockets*; a long swimming tail.

CLASS VI. **AVES.** *Birds* are *homothermous* animals, with the body covered with *feathers:* a complete *double circulation,* the heart having two auricles and two ventricles. The bones of the arm and hand are adapted for *flying.* All are *oviparous.*

SUBCLASS 1. **ARCHÆORNITHES.** *Extinct* birds with *toothed jaws* and the *caudal vertebrae* frequently forming the skeleton of a tail. They represent intermediate conditions between reptiles and birds.
Example: Archæopteryx, a *fossil* found in Bavaria in Jurassic formation. The hand has four fingers.

SUBCLASS 2. **NEORNITHES.** *Toothless* and the caudal vertebrae are reduced to a *pygostyle.* Includes all living birds.

CLASS VII. **MAMMALIA.** *Mammals,* are *homothermous* animals with *mammary glands* for nourishing the young, and the body covered in varying degrees with *hair* at some stage in development. The circulation is *completely double* and, as in birds, the heart consists of two auricles and two ventricles. A *diaphragm* separates the thoracic and abdominal cavities.

SUBCLASS 1. **PROTOTHERIA.** *Oviparous mammals* with a *single opening* for the urogenital system and alimentary canal. The mammary glands have no distinct nipples.
Example: Ornithorynchus paradoxus, the Australian *duckbill,* a curious creature with webbed feet and a bill like a duck's.

SUBCLASS 2. **EUTHERIA.** *Viviparous* mammals; the *anus* and *urogenital* openings distinct; the mammary glands with teats.

Division 1. Didelphia. The *vagina* is partially or completely *double*, and there is usually no placenta in development. The young are born in a very immature condition and are usually carried in an *abdominal pouch* by the mother.

Examples: Didephys virginiana, the American opossum. *Macropus,* kangaroo.

Division 2. Monodelphia. The *vagina* is single and the fœtus is nourished by an *allantoic placenta.*

SECTION A. **Unguiculata,** clawed forms.

Order 1. **Insectivora.**
Examples: Hedgehogs, shrews, moles.

Order 2. **Dermoptera.**
Example: Galeopithecus, an East Indian insectivorous-like form, with the fore and hind limbs connected by a membrane.

Order 3. **Chiroptera.** *Flying mammals,* in which the anterior limbs are modified into supports for membranous wings.
Example: Bats.

Order 4. **Carnivora.** Flesh-eating mammals.
Examples: Wolves, dogs, cats, lions, bears (some are herbivorous) etc.

Order 5. **Rodentia.** Have gnawing incisor teeth.
Examples: Mice, rats, rabbits, beaver, porcupines, etc.

Order 6. **Edentata.** Incisors, and occasionally all the *teeth lacking.*
Examples: Ant eaters, sloths, armadillos, etc.

Order 7. **Pholidota.** Body covered with bristle-like hairs; five *prismatic molars* in each jaw.
Example: South African *aardvark.*

Order 8. **Tubulidentata.** Body scaly, with scattered hairs. *Toothless.*
Example: Pangolin, the scaly ant eater.

SECTION B. **Ungulata,** hoofed forms.

Order 9. **Artiodactyla.** Axis of the foot passes through the third and fourth digits.
Examples: Swine, hippopotamus, deer, cattle, etc.

Order 10. **Perissodactyla.** Axis of the foot passes through the middle digit (third).
Examples: Horse, zebra, tapir, rhinoceros, etc.

Order 11. **Proboscidea.**
Examples: Elephants.

Order 12. **Sirenia.** Fin-like fore limbs; hind limbs lacking.
Example: Manatee.

Order 13. **Hyracoidea.**
Example: Hyrax, the coney of the Bible.

SECTION C. **Cetacea.**

Example: Whales. Fore limbs paddle-like; hind limbs lacking., nostrils on the top of head; caudal fin in two lobes or *flukes.*

Order 14. **Odontoceti.**
Example: Toothed whales.

Order 15. **Mystacoceti.** Functional teeth lacking, the upper jaw bearing plates of *whaleen* (whale bone).
Example: Whale bone whale.

SECTION D. **Primates.**

Order 16. **Primates.**
Examples: Monkeys, apes, and *man.*

References

HARMER, S. F. and SHIPLEY, A. E. (Eds.): "Cambridge Natural History," ten volumes. The Macmillan Company, 1904.

KINGSLEY, J. S.: "Hertwig's Manual of Zoology." H. Holt and Company, 1909.

KINGSLEY, J. S.: "Vertebrate Zoology," H. Holt & Company, 1899.

LANCASTER, E. R.: "A Treatise on Zoology." A. & C. Black, 1093.

PARKER, T. J. and HASWELL, W. A.: "Textbook of Zoology," The Macmillan Company, 1921.

PRATT, H. S.: "A Manual of the Common Invertebrate Animals Exclusive of Insects," A. C. McClurg & Company, 1916.

VAN CLEAVE, H. J.: "Invertebrate Zoology," McGraw-Hill Book Company, Inc, 1924.

WARD, H. B. and WHIPPLE, G. C.: "Fresh Water Biology," John Wiley & Sons, Inc., 1918.

GLOSSARY

ABIOGENESIS. The spontaneous generation of living things from non-living matter, a theory held but not experimentally demonstrated.

ABORAL. A pole of the body farthest from the mouth.

ABSORPTION. The passage of a fluid into lining cells by osmotic or capillary action.

ACHROMATIC. Uncolored. Free of color.

ADAPTIVE. Having the quality of fitness; favorable to life processes.

ADORAL. A point of the body near the mouth.

AGAMIC. Without gametes. Asexual.

ALBINISM. The absence of pigment in the skin, hair, feathers, eyes, etc.

ALBUMIN. One of the blood proteins; found also in milk, muscle and other animal substances.

ALIMENTARY CANAL. Same as digestive tract.

ALLELOMORPH. One of a pair of alternative characters in Mendelian inheritance; said also of the genes which represent these characters in the chromosomes.

AMINO ACID. An organic acid in which one or more of the non-acid hydrogen atoms is replaced by the NH_2 group. *Glycine* ($CH_2.NH_2.COOH$); *Lysine* ($CH_2.NH_2.CH_2.CH_2.CH_2.CH.NH_2.COOH$).

AMITOSIS. Direct cell division, in which the formation of a spindle and chromosomes is lacking.

AMŒBOID. Having a flowing movement, such as occurs in *Amœba*.

AMPHIGONY. Reproduction from a fertilized egg. Sexual reproduction.

ANABOLISM. The constructive or reintegrative phase of metabolism.

ANALOGOUS. Similar in function.

ANASTOMOSIS. A joining or communication between vessels.

ANATOMY. The structure of organisms as determined by dissections.

ANIMAL POLE. The yolk-free region of the egg.

ANKYLOSIS. Abnormal immobility and consolidation of a joint.

ANTENNA. One of a pair of jointed appendages of the head of an insect, or crustacean.

ANTERIOR. Toward the head or front end of an animal.

ANTITOXIN. A complex compound, probably protein in nature, formed in the blood and capable of neutralizing the effect of a specific poison or toxin, especially such as is produced by pathogenic bacteria.

ANUS. The terminal opening of the digestive tract.

APICAL. Pertaining to or located at the apex.

ARCHENTERON. The cavity of the gastrula; blastocœl.

ARTERIAL BLOOD. Oxygenated blood. It may be carried by either arteries or veins.

ARTICULATE. To join; to unite by means of a joint.

ARTIFICIAL PARTHENOGENESIS. The development of an egg following artificial stimulation without the intervention of a sperm.

Assimilation. The transformation of digested and other absorbed food products into living substance.

Asymmetry. An arrangement of parts incapable of being divided by a plane into halves which are mirrored images of each other.

Atom. The smallest particle of a chemical element which can exist either alone or in combination with other similar atoms or with atoms of another element; the smallest particle of a chemical element which enters into the composition of a molecule.

Axial. Pertaining to an axis. The backbone is the axial skeleton of vertebrates.

Axon. A process of a nerve cell conducting impulses away from the cell body.

Bacteria. A group of microscopic plants, some of which are the causative agents in the production of certain diseases. They exist in three general forms as follows: *cocci*, which are spherical; *bacilli*, rod-shaped; and *spirilla*, spiral filaments.

Biconcave. Hollow on each side or end.

Bilateral symmetry. An arrangement of parts capable of being divided by a plane into right and left halves.

Binomial nomenclature. The method of designating organisms by two names, one for the Genus and the other for the Species. Ex., Leopard frog, *Rana pipiens*.

Biogenesis. The generally accepted principle that all living things are derived from living things; that only life reproduces life. (See Abiogenesis.)

Biogenetic law. In its modern form, the doctrine that an animal in its development repeats to a certain extent the history of its race. Also known as the *Law of Recapitulation*.

Biparental. Derived from two parents, male and female.

Blastocœl. The segmentation cavity within the blastula; archenteron.

Blastomere. One of the cells formed in cleavage of the fertilized egg.

Blastopore. The opening of the archenteron.

Blastula. The stage following cleavage, when the cells are arranged in the form of a hollow sphere.

Buccal cavity. Mouth cavity.

Carbohydrate. Sugars, starches, and cellulose. Organic compounds consisting of carbon, hydrogen, and oxygen; the hydrogen and oxygen being in the same proportion as in a molecule of water (H_2O).

Carnivorous. Flesh-eating.

Catalysis. The acceleration in rate of a chemical reaction by an agent which itself remains unchanged.

Caudad. Toward the tail.

Caudal. Pertaining to the tail.

Cell. A mass of protoplasm containing one or more nuclei.

Cell doctrine. That all organisms are composed of cells and the products of cells; that the cell is the functional and structural unit of the organic body.

Cellulose. A carbohydrate found in the walls of plant cells. Its occurrence in animal tissues is rare.

CENTIMETER. A unit of linear measurement in the Metric System. Abbr. *cm.*, (2.54 centimeters = 1 inch).

CENTIGRADE THERMOMETER. One in which 0° is the freezing point and 100°, the boiling point of water.

CEPHALAD. Toward the head or anterior end.

CEPHALIC. Pertaining to the head.

CERVICAL. Pertaining to the neck.

CHARACTERS or CHARACTERISTICS. Physical traits.

CHLOROPHYLL. An important plant pigment, concerned in photosynthesis.

CHORDATE. An animal in which the notochord is or represents the skeletal axis during some period of its life history. All vertebrates are chordates.

CHROMATIC. Pertaining to color.

CHROMATIN. The deeply staining substance of the nucleus which forms into chromosomes when the cell divides.

CHROMATOPHORE. A cellular organ containing pigment.

CHYME. Partly digested food as it occurs in the stomach and intestine.

CILIA. Hair-like processes of Protozoa and ciliated epithelial cells.

CIRCULATION. The movement of the blood or body fluid through a more or less complete system of vessels.

CIRRUS. A soft tentacle-like appendage

CLASS. One of the principal subdivisions of a phylum in the system of classification.

CLEAVAGE. The period of cell division following fertilization, during which the egg is converted into a blastula.

CLOACA. A common cavity into which open the urogenital ducts and the alimentary canal, in fishes, amphibia, reptiles, birds, and the lowest group of mammals (*Prototheria*).

COCOON. A case in which eggs are deposited and in which larvae may develop.

CŒLENTERON. A sac-like body cavity in which digestion and absorption of food take place. Same as gastrovascular cavity. (*Hydra*, *Planaria*, etc.)

CŒLOM. The body cavity of the vertebrate type, lined with mesothelium and containing the viscera suspended by mesenteries. It is entirely distinct from the digestive cavity of the alimentary canal.

COLLOID. A state of matter consisting of a dispersed system of molecular aggregates.

COLONY. A group of individuals of the same species, often organically connected, forming a unit of a higher order than the individual.

COMMENSALISM. The association of two or more individuals of different species, often for mutual benefit.

CONCAVE. Curved inward.

CONJUGATION. A temporary union of two Protozoa during which an exchange of nuclear material takes place.

COPULATION. The sexual act during which spermatozoa are transferred from the male to the female; or between two monœcious animals.

CORTEX. The outer region of a cell or organ.

CONVEX. Curved outward. Bulging out.

CRANIAL. Pertaining to the cranium, the portion of the skull enclosing the brain.

CRETINISM. A condition characterized by subnormal mental and physical development, and caused by thyroid insufficiency.

CUTICLE. The outer layer covering the surface of the organic body. It may be a secretion product of underlying cells, as in many invertebrates, or it may be composed of dead cells, as in the stratum corneum human skin.

CYTOPLASM. The extranuclear part of a cell.

DARWINISM. The explanation of evolution by the theory of *Natural Selection* as set forth by CHARLES DARWIN.

DEAMINIZATION. The process in the body by which amino (NH_2) radicals are split off the protein molecule, thus liberating non-nitrogenous portions capable of oxidation and energy production.

DIFFERENTIATION. In embryogeny the transformation of blastomeres into tissues and organs. In general, a change from *homogeneity* to *heterogeneity*.

DIGESTION. The result of the action of digestive agents on food which reduces food to a liquid condition capable of absorption and assimilation by living cells.

DIŒCIOUS. A bisexual condition in which the male and female organs, testis and ovary, are borne by different individuals.

DIPLOBLASTIC. Having two germ layers.

DIPLOID. The unreduced number of chromosomes.

DISTAL. Remote from point of origin or attachment.

DORSAL. Pertaining to the back.

DUCTLESS GLAND. A gland whose secretion is poured directly into the blood stream. An endocrine gland.

DYNAMIC. Pertaining to change or process. Characterized by energy or action.

ECOLOGY. The study of the relation of organisms to their environment, both animate and inanimate.

ECTODERM. The outer germ layer of the gastrula.

ECTOPARASITE. External parasite.

EGG. The female germ cell, either before or after fertilization.

EMBRYO. An animal in the early stages of its development before it is liberated from the egg membranes.

EMBRYOGENY. The formation of the embryo and the course of its development. Embryogenesis. Embryology is the study of embryogeny.

ENCYSTMENT. The formation of a protective covering about an organism.

ENDOCRINE GLAND. See ductless gland.

ENDODERM. The germ layer forming the lining of the gastrula and bounding the archenteron or blastocœl; lining of the alimentary canal.

ENDOMIXIS. A nuclear reorganization occurring in Protozoa without conjugation and therefore without synkaryon formation (fertilization).

ENDOPARASITE. Internal parasite.

ENDOSKELETON. An internal living skeleton such as is present in vertebrates.

ENTELECHY. A word adopted from ARISTOTLE by HANS DRIESCH to designate the "vital force," which he believes is necessary as an additional factor outside the range of known forms of energy to explain life.

Entelechy and the "soul" of Descartes are practically the same concept, except that Descartes entertained the fanciful notion that the soul resided in the pineal gland, which is a dorsal outgrowth of the roof of the forebrain and in all probability represents an ancestral eye.

Enzyme. An organic catalytic agent which accelerates chemical reaction in the body.

Epigenesis. The idea that an organism in its development starts as a relatively homogeneous initial plamsa which becomes heterogeneous as a result of the action of external environmental factors upon it. The opposite of preformation in development.

Epithelium. A layer of cells covering an external or internal surface of the body.

Eugenics. The science of improving the inborn qualities of the human race by better breeding.

Eustachian Tube. A duct connecting the middle ear cavity with the pharynx. It is a survival of the first gill cleft of the fish.

Eutheria. A subclass including the viviparous mammals.

Evagination. The outgrowth of a pocket of cells from a surface.

Evolution. The doctrine that organisms of today are derived by *descent* from those of the past; that organisms have *changed* from time to time; that, in general, higher organisms are *descended* from lower ones.

Excretory. Pertaining to waste substances formed in metabolism.

Exoskeleton. The lifeless external cuticle forming the protective covering and supporting framework of arthropods.

External respiration. The passage of oxygen from the air or water into the blood.

Factor. Any causative agent. Its effect is called response.

Family. A subdivision of an order in classification.

Fat. An organic compound consisting of carbon, hydrogen, and oxygen, in the form of a glyceric ester of a fatty acid.

Fauna. The animal organisms occurring in a given region or place.

Feces. The excrement or undigested food residue discharged from the alimentary canal.

Fermentation. The decomposition of organic compounds, usually through the action of enzymes (*ferments*).

Fertilization. The culmination of the series of events following the entrance of the sperm into an egg ending in the union of a male and of a female nucleus to form the first cleavage nucleus.

Flagellum. A greatly enlarged cilium occurring in Protozoa, and frequently as the tail of a spermatozoön.

Fluctuating Variation. A relatively slight variation of somatic origin which is not heritable.

Fœtus. The mammalian embryo in later stages of development when the body regions are well defined.

Fossil. The remains of an extinct organism or its tracts, etc., found usually embedded in the earth's crust.

Gamete. Male or female germ cell; sperm or egg.

Ganglion. A tissue mass composed principally of nerve cell bodies.

Gastric. Pertaining to the stomach.

Gastrula. In embryogeny, the double-walled sac resulting from the invagination of the single-layered blastula. The outer layer is ectoderm and the inner endoderm. Gastrulation is a fundamental process in development.

Gel. A more or less rigid colloidal state.

Gene. The germinal representative of an adult character.

Genotype. The factor or gene complex of an organism or a group of organisms. The germinal complex as contrasted with somatic.

Genus. A group of related species. A subdivision of a family in classification.

Germ Layer. One of the primary embryonic tissues, ectoderm, endoderm, or mesoderm, from which the tissues and the organs of the adult develop.

Gill. A plate-like or filamentous appendage of an aquatic animal bathed by water, and serving as an organ of respiration.

Gill clefts. Paired openings leading from the sides of the pharynx to the exterior. Present in all Chordates. In fishes gills are attached to the septa separating the clefts.

Gland. An organ whose cells secrete one or more substances that may be used by the organism (as in secretions of the glands of the alimentary tract), or that may be excretory in character (as in the metabolic products secreted by the kidney).

Glottis. A slit-like opening in the floor of the pharynx leading to the respiratory tubes and the lungs.

Gonad. The organ whose function is to produce germ cells. Ovary or testis.

Gustatory. Pertaining to the sense of taste.

Habitat. The natural abode of an organism as to the kind of environment in which it lives.

Haploid. The reduced number of chromosomes.

Herbivorous. Plant-eating.

Heredity. The occurrence or production in offspring of parental traits or characteristics.

Hermaphrodite. An organism provided with both male and female gonads.

Heterocercal. Said of the type of fish-tail in which the terminal part of the vertebral column takes an upward bend, making the tail-fin asymmetrical, the ventral portion much larger than the dorsal.

Heterogony. The alternation of amphigony with parthenogenesis.

Heterozygote. An organism which has received from its parents two unlike genes for a given character and which, in turn, produces two numerically equal classes of gametes with respect to the genes.

Hemocœl. A body cavity which contains blood. An invertebrate type of body cavity.

Homologous. Said of organs having a similar origin in development, though not necessarily a similar function.

Homothermal. Having a practically constant body temperature.

Homozygote. An organism which has received from its parents two like genes for any given character. Its gametes are, therefore, all alike with respect to these genes.

Hormone. An internal secretion of a gland which activates other organs, or the body as a whole, in a specific manner.

Hyaline. Glassy, translucent.

Hybrid. The offspring of parents which differ from one another in at least one heritable character.

Hydroid. Colonial cœlenterate made up of individuals resembling *Hydra*. A polp.

Hydrolysis. A double chemical decomposition reaction into which water enters.

Hypertonic. Having a higher osmotic pressure than normal, or than another substance.

Hypothesis. A tentative supposition provisionally adopted for explaining certain facts and for serving as a guide for further investigation. A stage in the development of a theory.

Hypotonic. Having a lower osmotic pressure than normal.

Immunity. The resistance of the body to infection by pathogenic organisms, natural or acquired, through the productions of antitoxins.

Infection. Implantation of disease, pathogenic organisms, or parasites from without.

Integrative action. Said of the function of the nervous system as a coordinating mechanism for unifying bodily activities.

Intercellular. Between cells.

Internal respiration. The interchange of oxygen and carbon dioxied between tissues and the circulatory fluid. *True* respiration.

Internal secretion. The product, usually, of a ductless gland which is absorbed by the blood. Hormone. Endocrine.

Intracellular. Within a cell.

Intussusception. Growth by the intercalation of substances throughout the tissues of an organism, as contrasted with growth by accretion—deposits of particles on the outside—such as occurs in crystals.

Invagination. The ingrowth of a pocket of cells from a surface.

Invertebrate. An animal without a backbone.

Ion. An atom or group of atoms bearing an electrical charge. *Hydrogen-ion concentration* refers to the number of free hydrogen ions in a solution which determines whether the solution is "acid" or "basic" in reaction.

Irritability. The power of protoplasm to respond to stimuli.

Isotonic. Having the same osmotic pressure.

Katabolism. The disintegrative phase of metabolism.

Kinetic energy. Energy possessed by a body by virtue of motion. Manifested by heat production in chemical reactions.

Lacteal. A lymph vessel of the intestine.

Lacuna. An intercellular space.

Lamellated. Arranged in layers.

Larva. A usually active stage in the development of an animal marked by the presence of larval organs and by the absence of adult ones. An immature but free-living stage in development.

Lateral. Pertaining to the side.

Law. A statement of an order or relation of scientific facts which, so far as known, is invariable.

LESION. A wound or local degeneration.

LINEAR. Arranged in a line or row.

LUMBAR. Pertaining to the region of the back posterior to the ribs.

LYMPH. In vertebrates a circulatory fluid similar to blood but lacking red corpuscles. Same as blood in many invertebrates.

MACROSCOPIC. Large enough to be seen with the unaided eye.

MANDIBLE. A biting mouth part in invertebrates. The lower jaw of vertebrates.

MATERNAL. Pertaining to or derived from the female parent.

MATRIX. The intercellular material of cartilage and bone. Intercellular substance.

MAXILLA. A mouth part of an invertebrate. The upper jaw of vertebrates.

MECHANISM. The hypothesis supported by many facts that the phenomena of life are due to the sum total of the physical and chemical properties of the constituents of protoplasm. It does not admit "vital force" as a factor in explaining life processes.

MENDELISM. A universal type or inheritance based on the fact that genes of inherited characters separate and combine as units in the germ cells.

MESODERM. The embryonic germ layer formed between the endoderm and ectoderm.

MESOGLŒA. A non-cellular layer lying between the ectoderm and endoderm of *Hydra* and related forms.

METABOLISM. The chemical processes of protoplasm which are made up of disintegrative and reintegrative phases, katabolism and anabolism, respectively.

METAGENESIS. The alternation of sexual and asexual generations in the life history of an organism. The alternation of polyp and medusa in *Obelia*.

METAMERISM. The repetition of parts or segments in a linear series, as in the segmentation of the earthworm, or the arrangement of vertebrae in the vertebral column.

METAMORPHOSIS. The more or less sudden change of the larva into the adult. The transformation of a tadpole into a frog; or of a caterpillar into a moth.

METAZOA. Animals whose bodies consist of more than one cell. All animals above Protozoa.

MILLIMETER. One-tenth of a centimeter. Abbr. *mm.*

MITOSIS. The ordinary form of cell division. Also called Karyokinesis.

MOLECULE. A group of atoms. The smallest particle of a substance that possesses the properties of the substance.

MONŒCIOUS. Having both ovary and testis in one individual.

MOTOR NEURON and NERVE. One carrying impulses away from the central nervous system and causing muscular contraction or glandular activity. Efferent neuron.

MUCOSA. The layer of cells lining the digestive tract of vertebrates.

MUTATION. A heritable variation of a discontinuous type caused by some sort of change in the germplasm.

MYOTOME. One of the segments in the body musculature of vertebrates.

NATURAL SELECTION. The natural process of eliminating the unfit. The survival of the fittest in nature.

NEPHRIDIUM. A tubular type of excretory organ such as occurs in the earthworm and which is the forerunner of the tubules of the vertebrate kidney.

NERVE. A bundle of nerve cell processes, axons, or dendrons, or both.

NEURAL CANAL. The cavity in the vertebral column containing the spinal cord.

NEURAL TUBE. The embryonic ectodermal tube from which the brain and spinal cord develop.

NEURON. A nerve cell, including cell body, axon, and dendron.

NOTOCHORD. A structure characterizing the phylum Chordata consisting of a cylindrical rod lying ventral to the neural tube. In all vertebrates except *Cyclostomata* it is replaced in varying degrees by the centra of the vertebral column.

NUCLEOLUS. A usually spherical body within the nucleus taking an acid stain. Chromatin takes the basic stain.

NUCLEUS. One of the two principal components of a cell, occupying a central position in the cytoplasm.

OLFACTORY. Pertaining to the sense of smell.

ONTOGENY. The development of the individual.

OÖCYTE. The developmental stage of the egg at the end of the growth period.

OÖGENESIS. The development of a mature egg from a primordial germ cell.

OÖGONIUM. One of the product of division of the female primordial germ cell.

OÖSPERM. A fertilized egg.

OÖTID. The final product of oögenesis, the mature egg.

ORDER. A subdivision of a class in classification.

ORGAN. A tissue complex which performs a definite function.

ORGANELLE. A protozoan organ.

ORGANIC. Of or pertaining to organisms.

ORGANISM. A living thing.

ORGANOLOGY. The study of organs.

OSMOSIS. The slow passage or diffusion of fluids through semipermeable membranes. Osmotic pressure results from the difference in behavior of solvent and solute with respect to the membrane, the latter not being equally permeable to both. The surfaces of cells constitute the membranes through which substances must pass in and out of cells, the direction being determined by conditions within the cell with reference to the surrounding medium.

OVARY. The organ in which eggs develop.

OVIPAROUS. Egg-laying.

OVUM. Egg, female gamete.

OXIDATION. The chemical combining of a substance with oxygen, partial or complete. Combustion.

PÆDOGENESIS. Reproduction in the larval state.

PALEONTOLOGY. The science of extinct organisms.

Parasitism. An animal association in which one member, the *parasite*, derives nourishment from the tissues of the other, the *host*, to the detriment of the latter.

Parthenogenesis. Development of an egg without fertilization.

Paternal. Pertaining to, or derived from, the male parent.

Pathogenic. Disease-producing.

Pelagic. Said of the habitat of organisms living at or near the surface of large bodies of water.

Pelvis. The posterior region of the abdomen in vertebrates. The pelvic girdle.

Penis. An intromittent organ of the male by means of which spermatozoa are transferred to the vagina of the female.

Pericardium. In vertebrates the peritoneal sac surrounding the heart.

Peristalsis. The rythmic contraction of the intestinal wall.

Peritoneum. The membrane lining the cœlom of vertebrates.

Pharynx. The region of the alimentary tract between the mouth and œsophagus.

Phenotype. The somatic complex of an organism or a group of organisms regardless of the potential germinal possibilities.

Photosynthesis. The synthesis, or building up, of complex organic compounds from relatively simple inorganic substances through the agency of sunlight in the presence of pigments like chlorophyll. A natural process in plants.

Phylogeny. The developmental history of the race.

Phylum. A main subdivision of a plant or animal kingdom.

Placenta. A composite maternal and fœtal organ of the mammalian uterus which serves to attach the embryo, to supply nourishment and oxygen from the maternal blood, and to remove waste products. It is shed in whole or part at birth.

Placoid scale. Consists of a rhombic basal plate of dentine (bone) from the middle of which a spine projects. In the spine is a pulp cavity with blood vessels. Chaıacteristic of *Elasmobranchs*. Forerunner of mammalian tooth.

Plasma. The liquid part of the blood. Blood *minus* corpuscles.

Plexus. A union of several nerves to form a network.

Poikilothermous. Having a changing body temperature.

Polar body. One of the minute cells formed in the maturation divisions of the egg.

Polarity. Differentiation at the two ends of an axis.

Polymorphic. Several forms. The existence of two or more types of individuals in a species, as in the honey bee.

Polyp. A Hydra-like cœlenterate.

Potential energy. The energy a body possesses by virtue of its position. A lifted weight has potential energy in proportion to the kinetic energy expended in lifting it. An organic compound possesses potential energy in a chemical form in proportion to the energy expended in establishing a certain spatial relation between atoms in the molecule.

Preformation. In its original form, the idea that development consisted in the unfolding of adult structures already preformed in the germ;

which, of course, can no longer be maintained. In a modified sense the term can be applied to the organ-forming substances of many eggs and to the orderly arrangement of genes in a chromosome.

PROTEIN. An organic compound of large molecules made up of carbon, hydrogen, oxygen, and nitrogen, which upon hydrolysis yields amino acids. A very important constituent of protoplasm and one which has not yet been synthesized.

PROTOPLASM. Living matter.

PROTOTHERIA. The lowest group of mammals, which are viviparous.

PROTOZOA. Unicellular animals.

PROXIMAL. Next or nearest, as to a point of attachment.

PSEUDOPODIUM. A temporary finger-like extension of the cytoplasm of *Amœba* and related forms.

PULMONARY. Pertaining to the lung.

PUPA. The quiescent stage following the larval period in an insect, during which the adult organs are developed.

PURE LINE. All the offspring of a self-fertilized parent. A group of individuals having an identical germinal constitution.

PUTREFACTION. The decomposition of proteins as brought about by enzymes or bacteria.

RADIAL SYMMETRY. Symmetry that is referable to a circle. Two or more planes passing through a common axis will in each case produce halves that are mirrored images of each other.

RECTUM. The terminal portion of the alimentary canal in vertebrates and in many invertebrates.

REDUCING AGENT. A chemical agent which causes a loss of oxygen in a substance.

REDUCTION DIVISION. One of the two maturation divisions in gametogenesis during which synaptic chromosome mates separate, reducing the number to one-half.

REFRACTIVE. Having power to turn from a direct course. Said of the effect of certain substances on light.

RESPIRATION. The absorption of gaseous oxygen and the excretion of carbon dioxide by protoplasm.

RESPONSE. Any change in protoplasmic activity resulting from a stimulus.

RETICULUM. A network.

RUMINANT. A herbivorous animal that chews its cud.

SACRAL. The region of the vertebrate axial skeleton to which the pelvic girdle is attached.

SALIVARY GLANDS. Glands whose secretion is discharged into the mouth and which usually has some digestive property.

SEBACEOUS GLANDS. Oil-secreting glands present in hair follicles.

SECONDARY SEXUAL CHARACTERS. Traits other than the gonads that distinguish sexes.

SECRETION. The substance produced by a gland. The activity of a gland.

SEGMENTATION. See metamerism.

SENSORY. Pertaining to sensation. Said of a neuron carrying impulses from the periphery toward the central nervous system.

SEPTUM. Partition.

Serum. The clear fluid remaining after blood has clotted.

Sessile. Fixed; not free-swimming.

Sex-linked characters. Characters whose genes are linked with those of sex.

Sol. A more or less fluid colloidal state.

Solute. The substance dissolved in a liquid.

Solvent. The liquid in which a substance is dissolved.

Somatic. Pertaining to the soma or body as distinguished from germ cells.

Species. A group of individuals derived from similar parents, or practically alike in all important characters.

Sperm. Male gamete. Spermatozoön.

Spermatid. The male germ cell after the second maturation division but before its transformation into a spermatozoön.

Spermatocyte. The male germ cell at the end of the growth period.

Spermatogenesis. The development of a mature sperm from a primordial germ cell.

Spermatogonium. One of the products of the division of the male primordial germ cell.

Spontaneous generation. Same as abiogenesis.

Static. Pertaining to a body at rest or in equilibrium.

Stimulus. Any disturbing influence producing a reaction in an organism.

Stratum. A layer.

Striation. Striping, such as the cross-marks of skeletal muscle.

Symbiosis. The association of two species of organisms for mutual benefit.

Synkaryon. The fertilization nucleus formed by the union of male and female germ nuclei.

Systematist. A student of taxonomy. An expert in classification.

Tactile. Pertaining to the sense of touch.

Taxonomy. The science of classification.

Theory. A general principle serving as a plausible explanation of phenomena, supported by facts and by relevancy of reasoning.

Thorax. In mammals, the anterior division of the cœlom separated from the abdomen by the diaphragm and containing the heart and the lungs. In arthropods, the middle body segment.

Tissue. A group of histologically similar cells.

Umbilical cord. A rope-like connection between the mammalian embryo and the placenta carrying embryonic blood vessels, by means of which the nutritive and respiratory needs of the embryo are supplied. The umbilicus or navel on the abdomen of the adult marks the point of attachment of the cord.

Unguiculate. Provided with claws.

Ungulate. Provided with hoofs.

Unit character. A hereditary trait that maintains its integrity from generation to generation.

Ureter. The duct leading from the kidneys to the cloaca, or to the urinary bladder.

Urethra. The duct leading from the urinary bladder to the exterior.

Urine. The secretion of the kidney consisting of water and other katabolic products.

UROGENITAL. Pertaining to the excretory and reproductive systems.

UTERUS. In mammals, a specialized portion of the oviduct or oviducts in which the placenta forms and the embryo develops. In the frog, a portion of the oviduct in which eggs are held before deposition.

VACUOLE. A small cavity or space in a cell containing fluid or other substances.

VAGINA. The terminal portion of the female genital tract leading from the uterus or oviducts to the exterior.

VASCULAR. Pertaining to blood vessels, or blood supply.

VAS DEFERENS. A duct in the male leading from the testis to the exterior

VEGETATIVE. Nutritive. Said of the pole of the egg in which the yolk is concentrated.

VENOUS BLOOD. Deoxygenated blood.

VERTEBRATE. An animal with a backbone or vertebral column.

VISCERA. Internal organs, In mammals, the contents of the abdomen.

VITALISM. The doctrine that living phenomena can only be explained by assuming the presence in protoplasm of a "vital" factor of some sort in addition to the factors made up of the chemical and physical properties of protoplasm.

VIVIPAROUS. Bearing young alive.

ZOÖID. One of the members of a hydroid colony.

ZYGOTE. The fertilized egg, or the individual produced from the egg.

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